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TUNGSTEN CARBIDE TOOLS

By Roger D. Prosser

Abstract

The great interest which has been aroused by the development of cemented tungsten carbide at the Krupp Works has resulted in considerable discussion of the freak or "trick" results obtainable with these tools. In this paper, the author confines himself principally to a description of some of the results being obtained in every day actual production work, and gives very definite and practical advice as to the methods of application, grinding and use which should be employed to take full advantage of the remarkable properties of these tools. A brief history of the development of cemented tungsten carbide tools is also given, with a description of some of their characteristics.

So much has been said and written regarding the sintered or cemented tungsten carbide tool metals since this class of material[1] was first placed on the market by the Krupp Works about the end of 1926 that practically everyone interested in metal working has heard more or less about this material and what it will do under test conditions. This paper will therefore be devoted principally to the practical application of these tools to actual shop work.

The great hardness of tungsten carbide itself has been known for many years but its application to metal cutting tools was extremely limited, due to its brittleness and porosity. Many cast compositions of tungsten carbide have been tried, but all were brittle

[1]Due to the great hardness of this material, Krupp named their product "Widia", which is a contraction of the words "wie diamant", meaning "like a diamond".

A paper presented before the Boston chapter of the society, June, 1929. The author, Roger D. Prosser, is associated with the firm of Thomas Prosser and Son, New York City.

and far from homogeneous. Therefore, it became apparent that the possibility of using tungsten carbide for cutting tools would depend upon increasing the toughness through special methods of alloying and manufacture. Credit for the original discovery of a method of improving the properties of tungsten carbide through the use of cobalt must be given to scientists of the Osram Company of Berlin. The metal produced was called "Hartmetall" and was considerably tougher than tungsten carbide itself, but which was still not all that could be desired. It was principally used for wire drawing dies.

The Krupp Steel Works undertook extensive research in their laboratories for a tougher combination and one more suitable for metal cutting tools. These investigations finally resulted in the development of a product which attained great toughness, at the same time retaining the original hardness of tungsten carbide to a remarkable degree. After leaving the laboratory, this revolutionary product was then tested for months in actual production work before being placed on the market by Krupp in a commercial way.

Arrangements have been made with Krupp whereby it is possible for several concerns to manufacture similar products in this country. The various products will, of course, not be identical, as their properties will depend upon the methods and compositions used.

Process of Manufacture

Cemented tungsten carbide is not made in bars, but is produced only in the form of small pieces for use as cutting edges for tools or as inserts for any part having to withstand wear or abrasion. It is not cast but is made by forming the finely divided and carefully mixed components to the shape desired, under powerful hydraulic pressure. It is then sintered in an inert atmosphere at great temperature, resulting in a product which is so hard that its shape cannot be changed by the usual means. It must be ground on special wheels developed for the purpose. The methods and purity of the materials used and state of pulverization greatly effect the resulting product, as the finely divided pure tungsten carbide must be evenly distributed throughout the cementing matrix of cobalt. Fig. 1 shows the structure of the cemented tungsten carbide as compared with a cast tungsten carbide composition (Fig. 2).

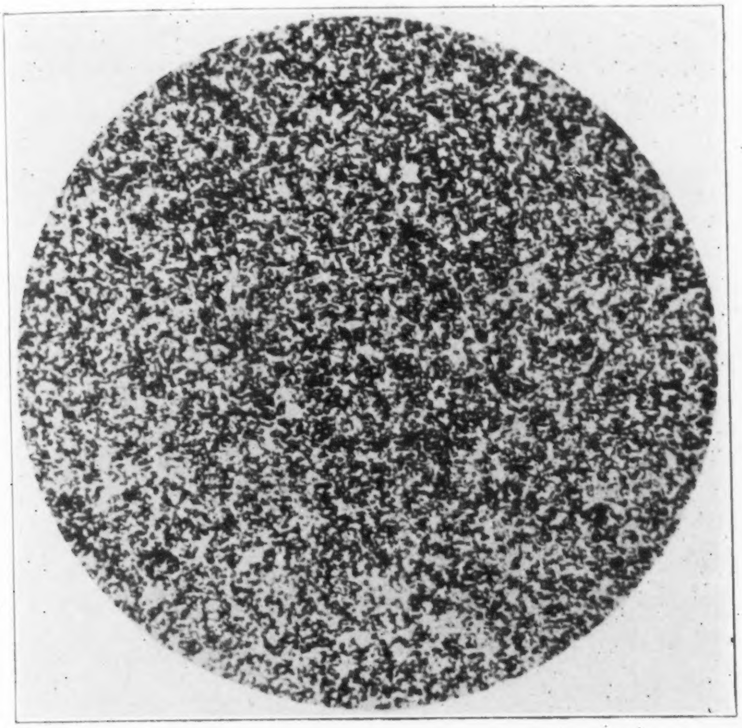


Fig. 1—Photomicrograph of Cemented Tungsten Carbide. × 750.

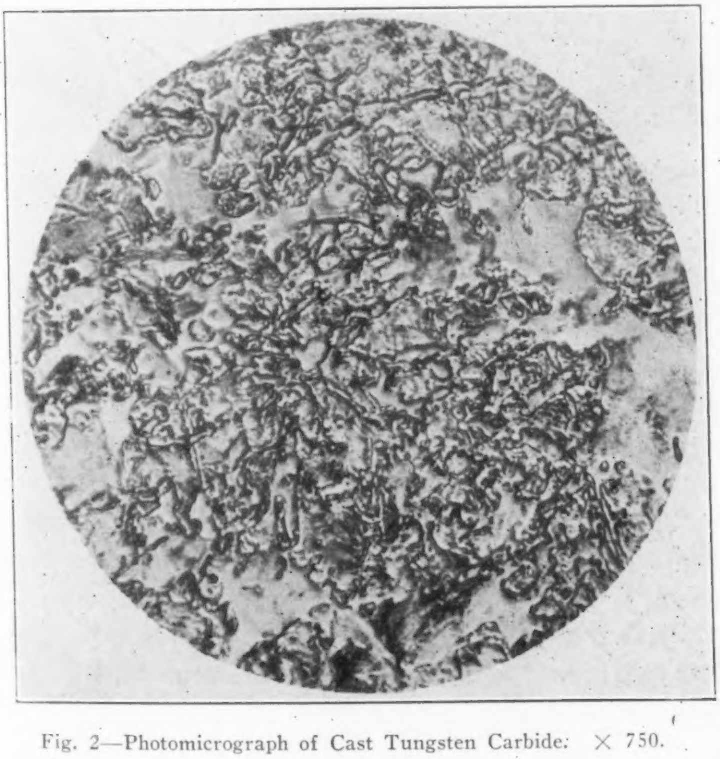


Fig. 2—Photomicrograph of Cast Tungsten Carbide. × 750.

Results to be Obtained

The practical man will be more interested in actual results than in history, and production records rather than test results will be given.

One shop in this country which manufactures automobile parts, has tooled-up every machine in the shop. As the result, the production of the entire shop has been more than doubled, according to the manager. This doubled production has been accomplished without any new machinery and without additional labor.

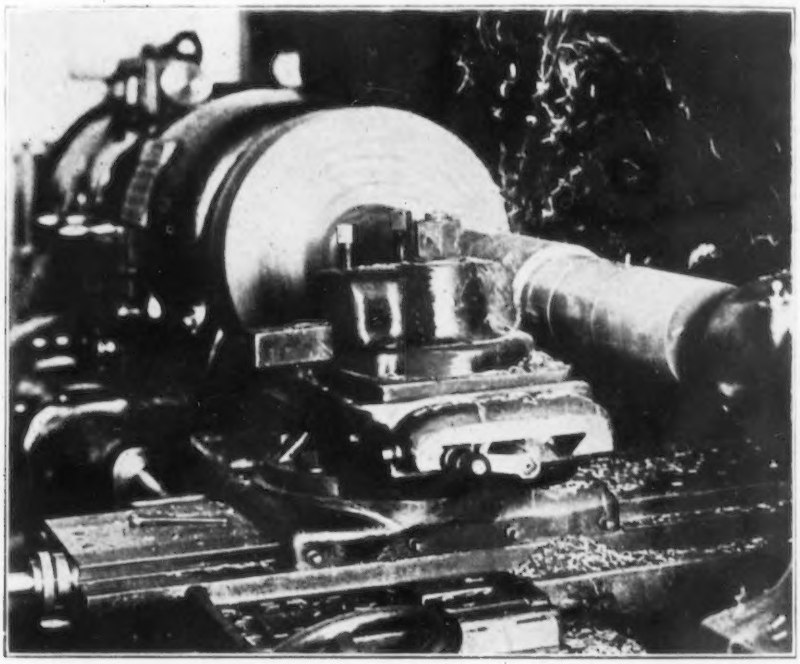


Fig. 3—Intermittent Cutting on Lathe Amounting to Over 400 Impacts per Minute on Cutting Edge.

Another instance of speeding up production is in the manufacture of an automobile transmission drum. With the best alloy tool steel previously available, this drum, which is of cast iron, cast in a permanent mold and very hard on the surface, was machined at a cutting speed of 190 feet per minute. With tungsten carbide tools this is being done at 592 feet per minute. The previous production time was 78 seconds, whereas this part is now being made in 20 seconds, or practically four times as fast as before. In addition, the previous tool needed regrinding after every 25 drums machined, whereas the tungsten carbide tool only needed regrinding after every 100 drums

Table I
Cutting Efficiency of Various Tools
Material Machined was Cast Iron

	Cutting Efficiency Cubic Inches of Metal Removed Per Minute	Cutting Time Before Breakdown in Minutes	Total Metal Removed in Pounds
Carbon Tool Steel	0.0032	1.7	1.43
High Speed Steel	0.0155	3.2	13.4
Original "Hartmetall"	0.0205	7.5	41.8
Cemented Tungsten Carbide	0.0286	16.5	127.6

machined. This was without change in equipment, other than the change to the new tools, and speeding up the machines.

A very useful field for tungsten carbide tools is in machining the soft but abrasive materials. A particular application of this nature is in a large die casting shop. The job is machining the fins from small aluminum die-castings, and the greatest number of pieces which had ever been machined before the tool needed regrinding was 2500. A tungsten carbide tool was put on the job, and at the last report had machined 45,000 pieces, had never been out of the machine, and the edge was still in good condition, producing a smooth finish on the work.

In the manufacture of bronze bushings using cemented tungsten carbide tools, the machines have been speeded up to five times the previous speeds, and where regrinding was formerly necessary after every 15 pieces, it is now only necessary to grind the new tools after every 500 pieces.

In machining cast iron test logs with a tungsten carbide tool these pieces, 12 inches in diameter with two cast longitudinal slots 1⅜ inches wide and having a Brinell hardness of 220, are machined at a surface speed of 655 feet per minute, with a depth of cut of 0.59

Table II
Cutting Efficiency of Various Tools
Material Machined was Open-hearth Steel with Tensile Strength of 80,000 Pounds Per Square Inch. Depth of Cut—3/16 Inch. Feed—0.021 Inch

	Cutting Efficiency Cubic Inches of Metal Removed Per Minute	Cutting Time Before Breakdown in Minutes	Total Metal Removed in Pounds
Carbon Tool Steel	0.0018	4.7	0.48
High Speed Steel	0.0066	10.1	3.86
Original "Hartmetall"	0.0117	10.6	7.27
Cemented Tungsten Carbide	0.0146	26.0	22.0

inches, and a feed of 0.036 inches. The tool is not injured by the intermittent service, which amounts to over 400 impacts per minute on the cutting edge, even when the cutting is carried on for long periods of time. This operation is shown in Fig. 3.

Some other examples of heavy work satisfactorily performed with tungsten carbide tools, under very good conditions, are 0.35 per

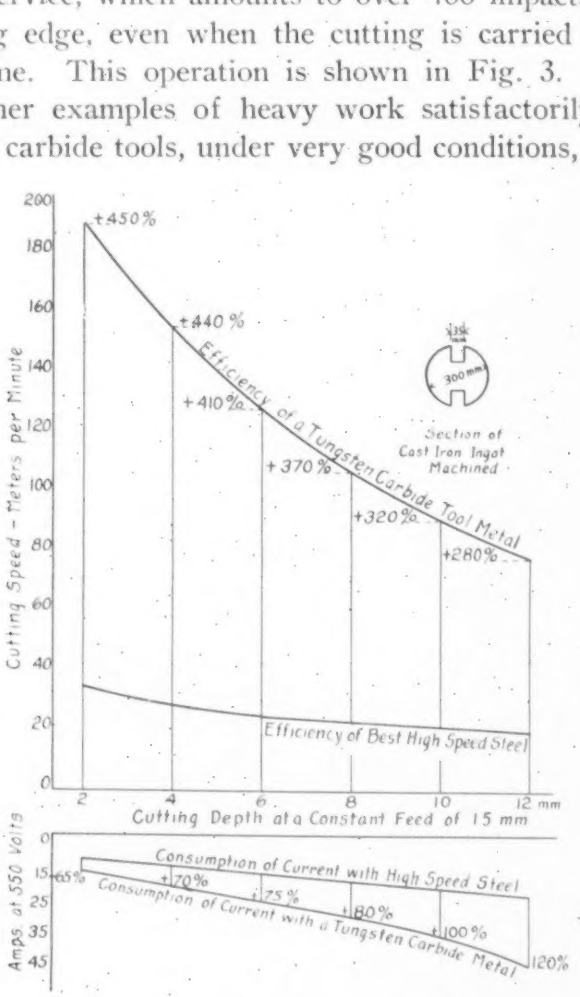


Fig. 4—Diagram Showing the Output Obtained with Tungsten Carbide and High Speed Steel Tools When Machining a Cast Iron Ingot at a Hardness of 250 Brinell and with a Double Interrupted Cut.

cent carbon steel cut at 100 feet per minute, 0.2-inch cut, and 0.16-inch feed, or 200 feet per minute, 0.4-inch cut and 0.060-inch feed. Chromium-nickel steel, 3.5 per cent nickel, 1.5 per cent chromium having a tensile strength of 140,000 pounds per square inch, cut at 65 feet per minute, 0.16-inch cut, and 0.160-inch feed, or 150 feet per minute, 0.4-inch cut and 0.040-inch feed. Stainless steel, about 18 per cent chromium and 8 per cent nickel, cut at 115 feet per minute, 0.20-inch cut, and 0.040-inch feed. Cast iron of 220 Brinell hardness, cut at 280 feet per minute, 0.70-inch cut, and 0.040-inch feed.

Manganese steel of the 12 per cent type is being cut regularly at 35 feet per minute, 0.2-inch cut, and 0.012-inch feed.

A few comparisons between cemented tungsten carbide and some other cutting materials with respect to cutting efficiencies and life of the cutting edge, may be of interest. Table I shows the average results of a number of tests with cast iron of medium hardness which was machined with carbon steel, high speed steel, original "Hartmetall," and tungsten carbide tools, until they required regrinding. The same feed and depth of cut were used for all tests.

Table II shows the results with open-hearth steel of about 80,000 pounds per square inch tensile strength. These tests were made with a uniform depth of cut of about 3/16 inch and feed of 0.021 inch.

It is an interesting fact that the work remains comparatively cool when being machined at high speeds with tungsten carbide tools, with consequent elimination of distortion.

While it is of course necessary to have increased power to drive the machines at higher speeds, when maintaining the same chip cross section, there is a decrease in power required per pound of metal removed. For example, in extensive tests on the operation of roughing a carbon steel shaft of about 85,000 pounds per square inch tensile strength, 42 inches long and 3¼ inches in diameter, the results were as shown in Table III.

Table III
Rough Turning A Carbon Steel Shaft
Tensile Strength 85,000 Pounds Per Square Inch

	With Highspeed Steel Tools	With Tungsten Carbide Tools
Metal Removed per Hour	94.6 Pounds	160.8 Pounds
Actual Cutting Time	23.8 Minutes	14.0 Minutes
Time from Floor to Floor	44.6 Minutes	33.4 Minutes
Total Metal Removed	37.5 Pounds	37.5 Pounds
Total Power Used per Shaft	1.58 Kilowatt Hours	1.20 Kilowatt Hours
Power Used per Pound of Metal Removed	0.0422 Kilowatt Hours	0.032 Kilowatt Hours

Decrease in Power Required with Tungsten Carbide Tools—24.2 Per Cent

The increased efficiency of cemented tungsten carbide tools as compared with the best high speed steel tools, when machining a cast iron log of 250 Brinell hardness, about 12 inches in diameter and with two interruptions, is shown in Fig. 4. It will be seen that the increased quantity of metal removed per minute does not produce a corresponding increase in power required. It will also be seen that the increase in efficiency of tungsten carbide tools as compared with

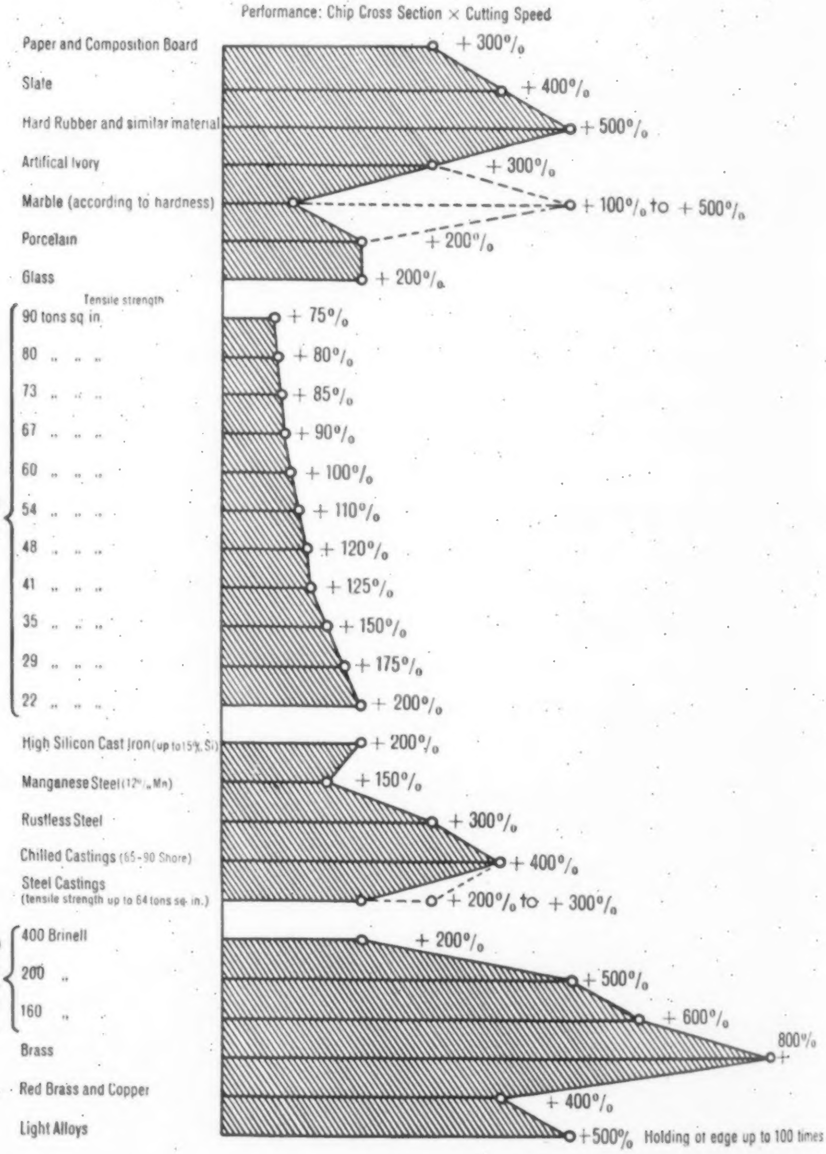


Fig. 5—Diagram Showing the Average Increase in Cutting Speeds which can be Expected on Various Materials when Using Tungsten Carbide Tools Under Good Conditions. Comparisons are with the Best Performance of High Speed Steel Tools.

high speed steel decreases as the depth of cut is increased, confirming the general principle of "high speeds and light cuts".

Depth of Cut (Inches)	0.08	0.16	0.24	0.32	0.40	0.48
Greater Efficiency (Metal removed per minute)	450%	440%	410%	370%	320%	280%
Increased Power Consumption only	65%	70%	75%	80%	100%	120%

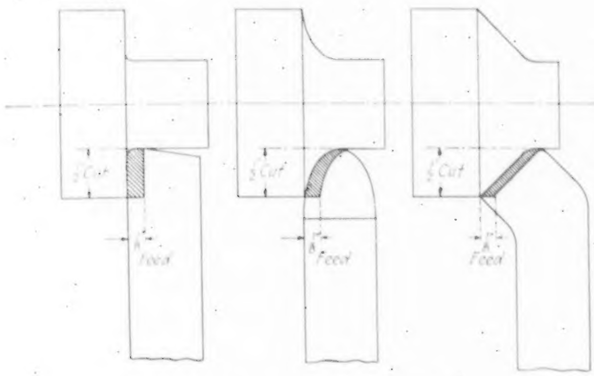


Fig. 6—Distribution of Chip Pressure on Different Shapes of Cutting Tools, each Taking the Same Feed and Depth of Cut. Pressure is better Distributed on the Right Hand Tool than on the other Two.

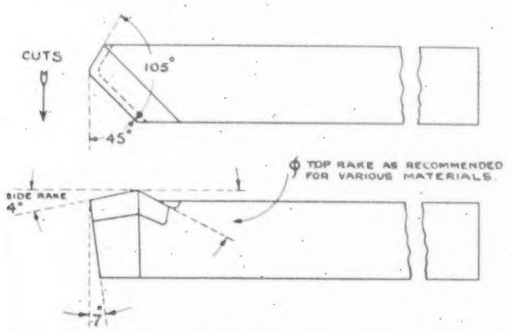
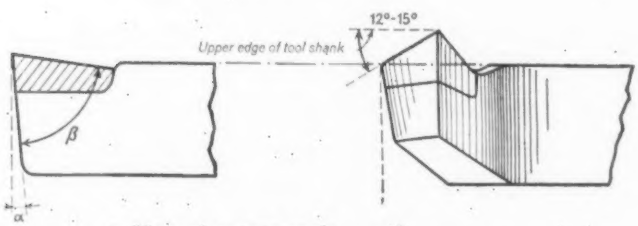


Fig. 7—Sketch of a Tungsten Carbide Tool Good for Heavy Work.



α Max. clearance angle....4°.
β Tool angle....as recommended in Table IV.
Side rake of top of tool 12°–15°.

Fig. 8—Suitable Tool Angles for Planing or Shaping. For this Work it is Necessary to Lift the Tool from the Work on the Back Stroke to Protect the Cutting Edge.

Effect on Machine Tool Design

In the light of some of the figures given it is obvious that cutting tools are again in advance of machine tool design, and many of the machine tool manufacturers here and abroad are busy designing equipment which will be able to make full use of the possibilities of tungsten carbide.

Frederick W. Taylor in his classic treatise "On the Art of Cutting Metals" published in 1906, says: "Undoubtedly high cutting speeds tend far more than slow speeds toward producing minute and rapid vibrations in all parts of the machine, and these vibrations are best opposed and absorbed by having large masses of metal supporting the cutting tool and the head and tail stocks. It is largely for the purpose of avoiding vibration and chatter in machines that the high cutting speeds accompanying the modern high speed tools call for a redesigning of our machine tools. While it is true that in many cases a very great gain can be made by merely speeding up a machine originally designed for slow speed tools, this increase in speed almost invariably produces a corresponding increase in the vibration or chatter, and for absorbing this, the lathes and machines of older design are, in many cases, too light throughout." This is as true now as it was then, and important developments in machine tools are being made to keep pace with the improvements in cutting tools.

At the present time, however, every machine shop is likely to be full of good machines which are being run to only a portion of their full capacity, and where there is plenty of power available. In such places the new tools can save money without the necessity of purchasing new machine tools.

Practical Recommendations for Use

It is necessary to emphasize strongly that many ideas in connection with the use of high speed steel must be revised when using tungsten carbide. It is not a steel, and as the process of manufacture would indicate, it has a structure entirely different from steel, necessitating different methods of use. The men in the shop wish to take a tungsten carbide tool and grind it to the same shape as used with high speed steel and put it in service on the toughest job in the shop. They expect the tool to perform wonders, and quite often they are disappointed. It is necessary to study each job carefully and work out the best possible conditions for tungsten carbide, at the same time educating the men as to the proper use of the tools.

Cemented tungsten carbide is only about half as strong as high speed steel, and the maximum pressure of the chip on the surface of the tool should be correspondingly less than the maximum chip pressure on the surface of a high speed steel tool. Ordinarily the pressure on a high speed steel tool is far from the maximum allowable,

the principal limiting factor being the cutting speed. In these cases, tungsten carbide tools can be used with the same feed and depth of cut, and at greatly increased cutting speed.

Fig. 3 gives in condensed form the increase in cutting speed which can be expected under the above conditions, when machining various materials and when maintaining the same feed and depth of cut as usual. This table is based on the best performance of high speed steel. It shows the minimum which can be expected consistently with cemented tungsten carbide tools if conditions are reasonably good, and will be found a good guide for ordinary use. These figures can often be greatly exceeded under proper conditions.

Where the chip pressure on the tool approaches the maximum allowable with high speed steel, it is necessary to make provision for a proper reduction in the pressure, if it is desired to speed up production by replacing the high speed steel tools with tungsten carbide tools. This reduction in pressure can be accomplished by using finer feeds, or by the use of a different form of tool. A somewhat decreased feed will often permit the use of a greatly increased cutting speed.

Fig. 6 shows the distribution of chip pressure on three different forms of tools, each taking the same depth of cut and the same feed. Fig. 7 shows an excellent form of tool for heavy service, where the cutting edge enters the work at an angle of about 45 degrees. It will often be impossible to use this form of tool, due to the necessity of cutting up to a shoulder, etc., but it should be employed for heavy roughing wherever possible.

The clearance angle of the tool should be kept within reasonable limits, so that the cutting edge will be properly supported by the steel of the shank. Proper tool angles for machining various materials are shown in Table IV. The tool angle β refers to the actual cutting

Table IV
Suitable Tool Angles for Use on Various Materials

Material to be Machined	Clearance Angle $\alpha \pm 1°$	Tool Angle β
Soft Steel	4°	60–65°
Hard Steel	4°	65–74°
12% Manganese Steel	4°	80–84°
Stainless Steel	4°	65–74°
Chilled Cast Iron	3°	82–86°
Soft Steel Castings	4°	68–73°
Hard Steel Castings	4°	73–78°
Grey Cast Iron	4°	74–80°
Bronze, Brass, etc.	6°	65–75°
Aluminum Alloys	8°	50–55°

lip, and may be on the front or side of the tool, depending on the direction in which the tool is to cut.

Fig. 8 shows the recommended angles for planing or shaping. For this service, it is necessary that the tool be lifted from the work on the return stroke, otherwise there is danger of breaking off the fine cutting edge.

Due to the high cost of the tools, there is a tendency to use a tool too small for the work. This is a bad condition, and it will be found economical in the long run to purchase a tool which is suitable for the job. This usually means a tool somewhat larger than a satisfactory high speed steel tool for the same work. Bits tipped with tungsten carbide for use in tool holders are being made, but are only recommended for very light work, and wherever possible the tool holder should be replaced with a solid steel tool with brazed tungsten carbide tip. The cost of such a tool is only slightly greater than that of the bit, and the better results and longer life well warrant the difference.

Tungsten carbide is a high speed material and its best application is in working at high speeds and light feeds. A deep cut with a light feed is better than a light cut with a heavy feed, as the chip pressure is distributed over a longer cutting edge. In general the principle of "high speeds and light feeds" should be borne in mind.

It should not be concluded from the above that it is not possible to use heavy feeds and cuts with tungsten carbide tools. On the contrary, it is possible, under proper conditions, to take very heavy cuts, even when the cuts are interrupted.

It is essential to have plenty of power, and to maintain the speed of the machine. Slowing down in the cut, vibration, and chattering, are conditions to be avoided. The machine should not be stopped with the tool in the cut and the feed on. These conditions should be observed regardless of whether a high speed steel tool or a tungsten carbide tool is used, but they are especially important when using the latter. The tool should be held short and firmly, and should be supported as near as possible to the cutting edge, avoiding the usual slotted form of tool post, and employing wherever possible a solid block with strong set screws holding the tool in place.

For outside turning, the cutting edge of the tool should be set 1 to 2 per cent of the diameter of the work above center.

In general tungsten carbide tools are used dry, no lubricant or

coolant being required. In a number of cases, however, especially on finishing cuts on steel, the use of soap water or a light cutting oil has proved of advantage, permitting a still further increase in cutting speed and lengthening the life of the edge.

Brazing

The tools are usually furnished complete, ready for use. The brazing operation requires care and if improperly done will give the impression that the cutting metal is at fault, whereas in reality the trouble is with the brazing. However, the operation is not difficult, and where the user fully understands the application of tungsten carbide tools, it is perfectly possible for him to have the brazing done in his own shop, should he so desire. Several important points should be kept in mind. For ordinary work, the shank should be of a good grade of 0.70 to 1.00 per cent carbon tool steel. High speed steel should ordinarily not be used for shanks, as it often causes trouble in the brazing.

The shank and tip should be carefully ground and cleaned so that the tip lies flat on the shank and makes close contact with its support. Copper should be used for brazing, and the heating should be done in a muffle furnace with a reducing atmosphere, at about 2100 degrees Fahr. It is necessary to protect the tungsten carbide from the direct flame, as otherwise there is danger of oxidation and damage to the material at the high temperatures involved. Borax is used as a flux, and should be thoroughly melted on the seat, which should then be scraped clean. The tip is put in place with a piece of copper and more borax on top, and the whole replaced in the furnace. When the copper has melted and the tip seems to be floating, the tool is removed from the furnace and the tip firmly pressed onto the shank. The tool is then immediately placed in powdered carbon for slow cooling. In general, open torches are not advisable, but where it is necessary to braze several tips to the same shank, or for small special tools, an oxy-hydrogen torch can be used to advantage. Care should be used to have an excess of hydrogen, and the shank should be thoroughly fluxed with borax. Tinned copper wire is used as a brazing medium.

Grinding

A sharp smooth edge is essential for best results with tungsten carbide tools, and this can only be obtained with special grinding

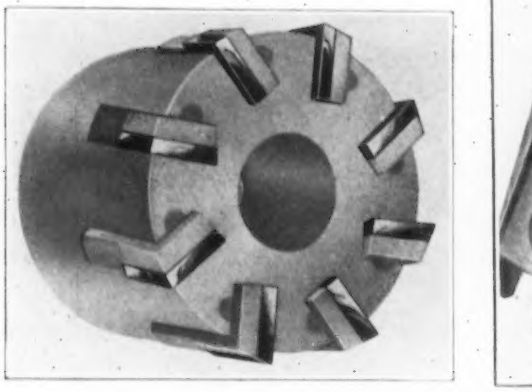


Fig. 9—Milling Cutter with Inserted Tungsten Carbide Tipped Teeth.

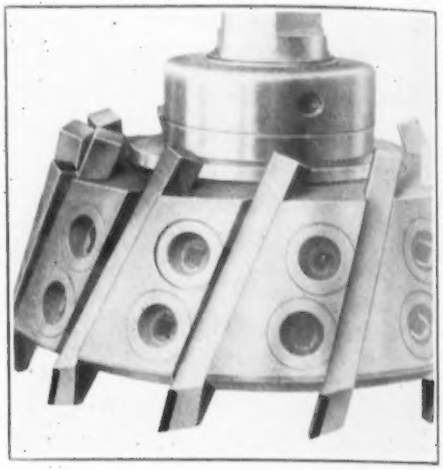


Fig. 11—Milling Cutter with Inserted Tungsten Carbide Tipped Teeth.

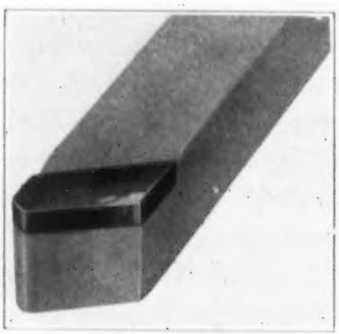


Fig. 10—Photograph of Tool Sketched in Fig. 7.

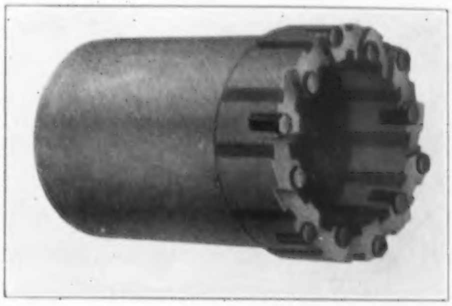


Fig. 12—Core-Drilling Head for Stone, with Inserted Octagon Tungsten Carbide Points.

wheels suitable for the purpose. The grinding can be done in about the same time as high speed steel, provided the special wheels are used, running perfectly true. The grinding can be done wet or dry, but wet grinding is recommended, using a plentiful supply of water directly on the part being ground, to avoid overheating and sudden cooling. A light pressure should be used, for the same reason. The metal can be cracked and rendered unfit for further use if these instructions are not observed.

Special Applications

Tungsten carbide is being used successfully on many special applications, and various new uses are constantly being developed. When working out any new applications, the characteristics of the

material should be taken into consideration. Very thin knife edges are not practical. Special forming tools can be made, but small intricate shapes should be avoided, as it is almost as difficult to grind these shapes in tungsten carbide as it would be to grind them in a diamond. Solid milling cutters, saws, etc., can in many cases be tipped with tungsten carbide but inserted teeth should be used wherever possible. Figs. 9 to 12 show several types of tungsten carbide tipped tools.

Diamonds have recently been coming more and more into use for various operations in the machine shop, such as finishing the bearing—metal and bronze bushings in connecting rods, for machining abrasive material such as bakelite, aluminum, bronze, and other similar applications. When boring connecting rod bushings with diamond tools, it is possible to use a very high speed, producing an exceptionally true bore and fine finish. Special rigid machines, free from vibration and capable of the high speeds, must of course be used. Tungsten carbide is now replacing many diamond tools, and these small boring tools can be run at just as high a speed as the diamond tools, which is from 2500 to 5000 revolutions per minute, depending on the size of the hole to be bored. A fine finish is produced, due to the ability of the metal to maintain its sharp cutting edge, with resulting free cutting and absence of tearing effect. The finish can also be improved by using a tool shape which will have a tendency to burnish the work, the same as is done with diamond tools. Interrupted cuts, such as encountered in split bearings, can be made without difficulty. The cost of a complete tungsten carbide boring tool is of course considerably less than that of a similar diamond tool.

Splendid results are being had in many cases with drills tipped with tungsten carbide, but it is too early as yet to predict whether they will come into general use in production work. At present they are only recommended for work where high speed drills are not satisfactory, such as drilling manganese steel and chilled cast iron, very tough materials such as stainless iron, and soft but abrasive materials like hard rubber, bakelite, aluminum, etc. They should be used only by skilled workmen and with plenty of lubricant.

Conclusion

In conclusion it should be said that tungsten carbide is not a cure-all. Where bad chattering is unavoidable, where old loose

machines are taking hogging cuts on steel to the limit of their capacity, and in some cases of high speed finishing on soft steel, there may be little or no advantage in using these tools. They should not be indiscriminately placed in a machine without considering the difference between cemented tungsten carbide and high speed steel. Each job should be considered carefully, bearing in mind the few simple recommendations for use. Then the tools will perform splendidly, cutting costs, speeding up production to a remarkable degree, and performing jobs which have hitherto been impossible.

SUGGESTED METHODS FOR REPORTING ON THE NITRIDED STEEL CASE

By George M. Eaton

Abstract

Current reports of research on the hardness-depth characteristics of the nitrided case are plotted on random scales. This hampers the rapid and critical comparison of the results of different reporters. At this early stage of the nitriding development, it seems desirable and practical to develop a uniform method of reporting. The suggestions in this paper are tentative and for the purpose of starting discussion.

The author feels that the nitriding committee of the American Society for Steel Treating is the logical body to develop a recommended practice for reporting on the nitrided case. The depth-hardness characteristic seems to be a logical starting point for this recommended practice and other features may logically follow. The depth-hardness characteristic as plotted on plain coordinates gives a misleading picture of the wear resistance of the case. The use of a logarithmic scale of hardness and a plain scale of depth is suggested. No defense is offered for the detail accuracy of the logarithmic scale for hardness. A practical scale of greater proven accuracy would be welcomed.

In the appendix, the possible use of the scleroscope, as an inspection tool, is discussed.

A merit index for wear resistance is suggested. This merit index is based on hardness alone and the utter necessity for some ductility of case is strongly emphasized.

Scales Used for Hardness and Depth

As one follows the literature which is accumulating on the hardness-depth characteristic of the nitrided case of various steels, attention is unavoidably focussed on the fact that the various reporters have adopted widely varying scales for plotting the results of their research. This is illustrated in Fig. 1, showing scales published in the American Society for Steel Treating Transactions for

A paper presented before the Semi-Annual meeting of the society held in New York City, Feb. 7 and 8, 1930. The author, a member of the society, was at that time connected with the Molybdenum Corp. of America, Pittsburgh. He is now associated with the Spang Chalfant Co., Ambridge, Pa. Manuscript received January 27, 1930.

Oct. 1929. It is not necessary to comment in detail on the variety of scales, as the facts are obvious. The characteristic curves plotted in Fig. 1 are not taken from the TRANSACTIONS, but are those used later in this paper for illustration purposes. (No characteristic curves are shown on the scleroscope hardness scale, because we have no applicable scleroscope-brinell conversion table) (See Appendix No. 1).

This is a perfectly natural development, and no criticism can be offered, up to the present time. It is true, however, that comparisons of the results of various researches can be made with much greater facility when a uniform method of reporting is established. With the widespread research now under way, it seems worth while to start a movement to this end.

Purpose of Paper

It is the purpose of this paper to:

1. Emphasize the need for the adoption of a uniform method of reporting.

2. Suggest a detailed method for the purpose of drawing out constructive discussion.

3. Propose a merit index for weighing wear resistance, also with the hope that by discussion, something widely acceptable may be evolved.

While we have adopted these detailed suggestions in our own work, after a good many trials of other plans, we hold no hard and fast brief for them, but we are interested in the broad adoption of some uniform procedure. We are prepared to go along on any logical line that becomes widely accepted. It is our ambition that this paper and the discussion which it may provoke shall pave the way for the Nitriding Committee of the American Society for Steel Treating to take over the formulation of a Recommended Practice for Reporting on the Nitrided Case.

Meaning of the Hardness-Depth Characteristic

The purpose of the hardness-depth characteristic, consciously or unconsciously, is usually to convey some approach to a visual picture of the wear resistance of the case under investigation. Unfortunately this picture is misleading when, as is the case in all the graphs we have seen, the characteristic is plotted on the usual plain cross section paper. The mind automatically pictures the area of the graph as

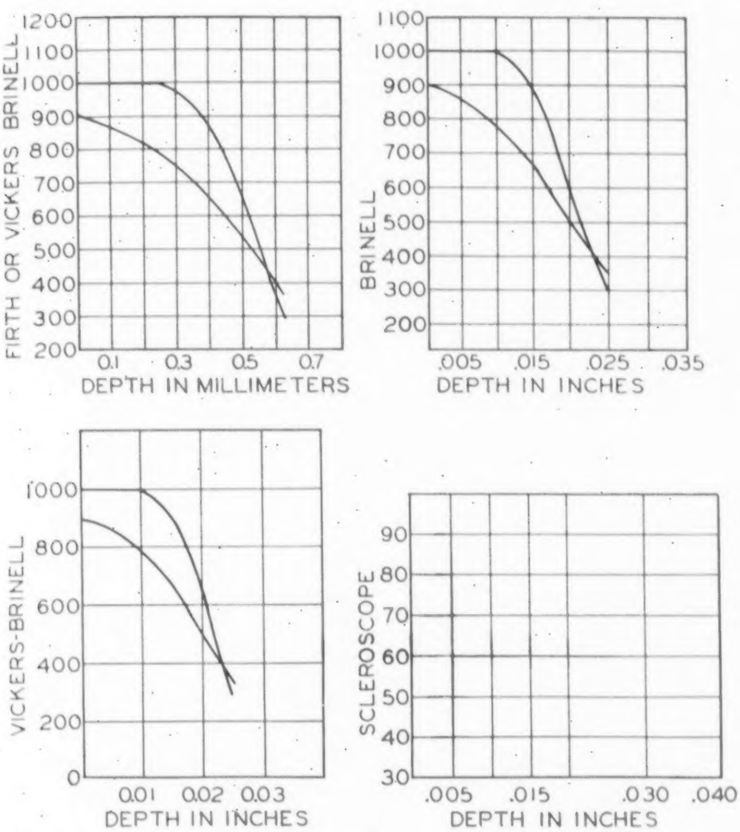


Fig. 1—Variety of Scales Used to Show Depth-Hardness Characteristics.

a general measure of wear resistance, but this means that a surface layer 0.001 inch thick and 900 to 1000 Brinell hard is credited with only twice the wear resistance of a layer of the same thickness, but closer to the core, and only 450 to 500 Brinell hard. It is beyond argument that a graph plotted on a scale which gives the case credit for a unit wear resistance increasing as some direct and progressive function of hardness, can be made more representative of the actual wear resistance than is possible with a graph plotted on plain coordinates.

Logarithmic Scale for Hardness

We know of but one commercially available progressive scale, viz., the logarithmic scale. We offer no defense for the detailed accuracy of this scale for our purpose, and welcome some practical scale which can be shown to approximate the truth better. The most that can be claimed for the logarithmic scale is that it is better than

the plain scale, and that its ready availability in the form of commercial semi-logarithmic paper makes it thoroughly practical for our use. We believe that the logarithmic scale, as we are suggesting its use, still somewhat underestimates the relative wear resistance of the

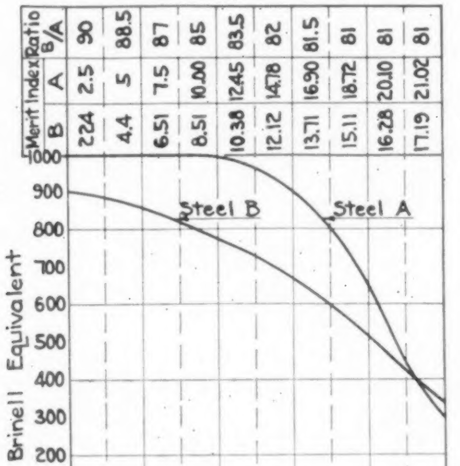


Fig. 2—Plain Hardness-Depth Characteristic.

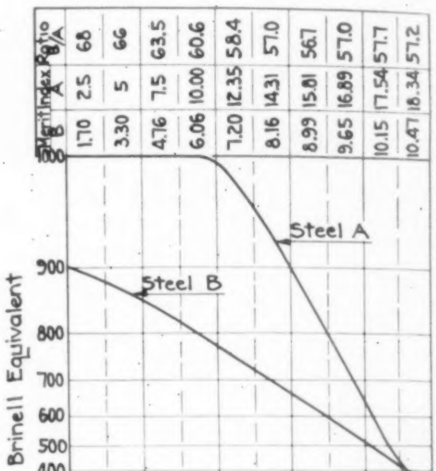


Fig. 3—Logarithmic Hardness-Depth Characteristic.

hard outer layers of the nitrided case, for types of wear to which the nitrided case is applicable.

To illustrate the difference in the graphs of hardness-depth characteristic, as plotted on plain and semi-logarithmic paper, we show Figs. 2 and 3. It will be noted that the hardness scales in these two Figs. are selected to indicate the identical concrete hardness value at 100 Brinell. The two steels chosen are hypothetical, as we wish in this connection to avoid all discussion of the relative merits of specific nitrided cases.

Merit Index for Weighing Relative Wear Resistance

We wish to derive for each of these steels a merit index which can become a useful tool for approximating the relative wear resisting tendencies of these steels for all applications. It is germane here to call attention to the fact that the wear resistance of steel is generally believed to be some composite function of hardness and ductility. We are unfortunate, at this stage of the nitriding development, in

lacking a quantitative measure of the ductility of the nitrided case. We are therefore forced to base our suggested merit index on hardness alone. This makes it vitally important to remember at all times, when using the merit index, that the utter brittleness indicated by persistent spalling around the Vickers indentation completely undermines the relation between the merit index and service performance. Having realized this somewhat discouraging situation, we may proceed with the discussion leading towards a merit index.

There are, in general, two classes of application of nitrided steel from the wear standpoint.

1. The class where there is a predetermined operating limit of tolerable wear. This may be illustrated by the piston pin of a gas engine, where only one or two thousandths of an inch of radial wear can be tolerated.

2. The class where the entire case will be worn away before replacement will be made. Rubbing or chafing plates, in applications where accumulated clearances can be tolerated, fall into this class.

It is perfectly clear that a merit index, to have any meaning, must be built around the limiting depth of wear which can be tolerated in any and all applications. In all scales for hardness plotting we assume that the distance (measured in inches) from the base line to any given Brinell value, is the measure of the relative unit wear resistance at the given Brinell. We have used zero Brinell as the base line in the plain plotting, and 100 Brinell as the base line in the logarithmic plotting, because these values are practically dictated by the demand for simple plotting operations on the two classes of coordinate paper we have used.

The merit index for a given limiting depth of wear is then the area (in square inches) below the depth-hardness curve, and between the vertical limit lines of zero depth and the given depth. This is true because this area represents the product of the unit wear resistance multiplied by the amount of metal worn off, at the operating limit. In Figs. 2 and 3 we show the cumulative areas for successive intercepts of wear of 0.0025 inch. In Fig. 4 we show the cumulative areas of Figs. 2 and 3, i. e., the merit index at each wear intercept, plotted against the depth of wear they represent. These curves show the merit index in usable form.

Fig. 5 brings out the difference between the plain and logarithmic merit indexes more sharply than Fig. 4. This Fig. shows the

ratio $\frac{\text{merit index for steel B}}{\text{merit index for steel A}}$ for both methods of plotting. It will be seen that there is a very real difference.

It will be noted that we have suggested no scale for hardness above 1000 Brinell in the logarithmic plotting. This is due to the rapidly increasing tendency for spalling with hardnesses above this value, and to our lack of knowledge of service wear resistance with

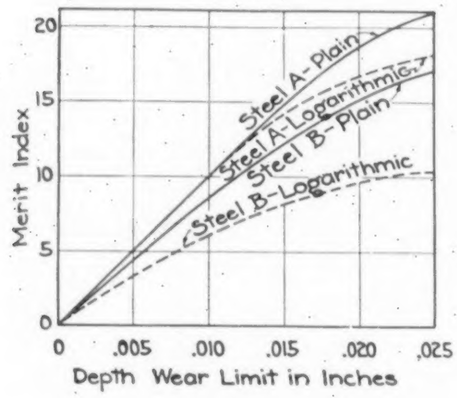


Fig. 4—Plain and Logarithmic Merit Index.

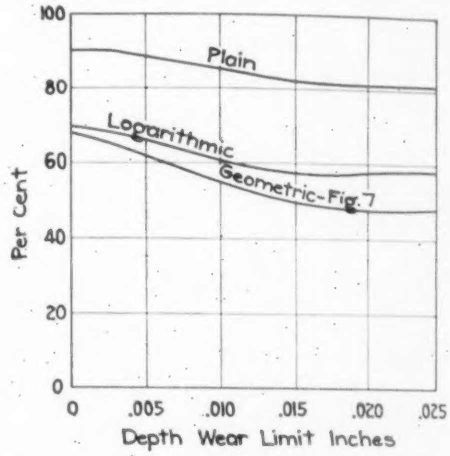


Fig. 5—Ratio $\frac{\text{Merit Index—Steel B}}{\text{Merit Index—Steel A}}$

hardness above 1000 Brinell, but we have left space on the common standard 7 by 10-inch coordinate paper for later development of a sensible scale.

In this connection it may be worth while ultimately for the American Society for Steel Treating to have a special coordinate paper printed for reporting on the nitrided case. If this is done we suggest consideration of proportioning the graphs in such a manner that they may be printed full size in the American Society for Steel Treating TRANSACTIONS, thus avoiding the complication of varying degrees of reduction in making the cuts. Then investigators will be able to compare published graphs directly with their own results.

GEOMETRIC HARDNESS SCALE

In order to compare the logarithmic scale with some other progressive scale, a geometric scale was developed on the basis of the following assumptions.

1. Unit wear resistance at 1000 Brinell the same as with the plain and logarithmic scales.

2. A constant ratio of increase of scale for each 100 points Brinell.

3. The 1000-point Brinell to indicate about five times the unit wear resistance of the 500-point Brinell.

Fig. 6 shows the hardness-depth characteristic plotted on this scale, which works out with a constant multiplier of 1.335. The merit

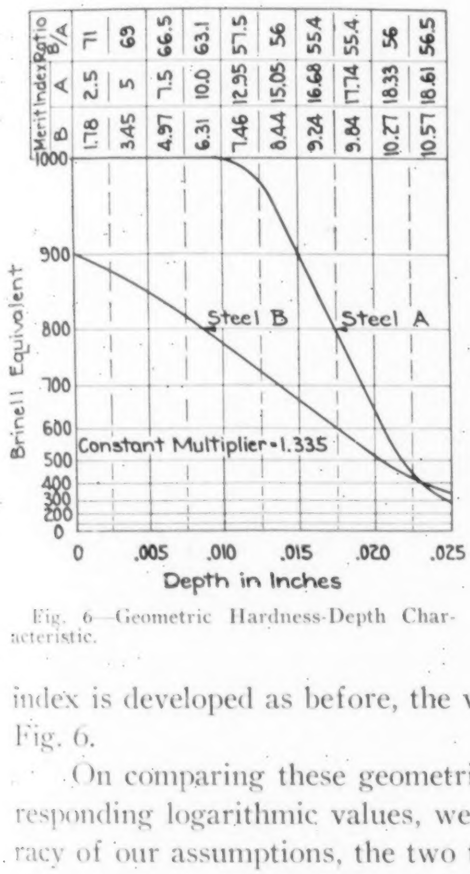


Fig. 6—Geometric Hardness-Depth Characteristic.

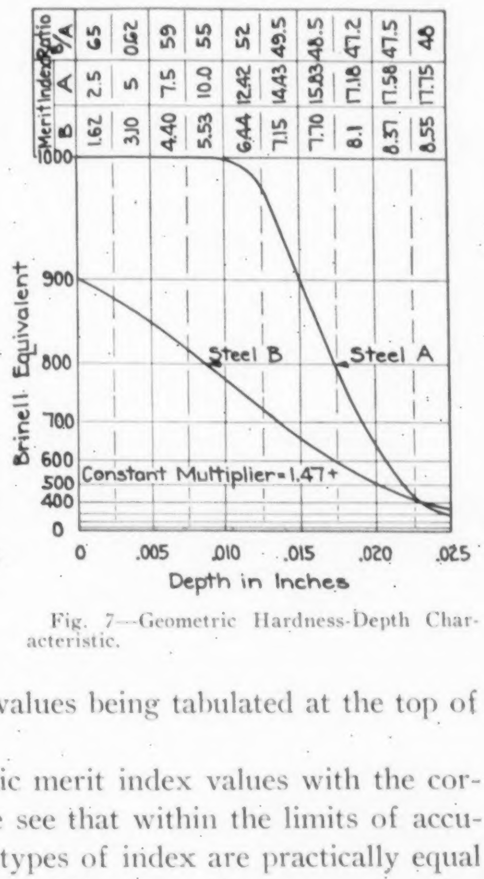


Fig. 7—Geometric Hardness-Depth Characteristic.

index is developed as before, the values being tabulated at the top of Fig. 6.

On comparing these geometric merit index values with the corresponding logarithmic values, we see that within the limits of accuracy of our assumptions, the two types of index are practically equal throughout the entire depth of case. Of course, the geometric index is quite flexible. By assigning a lower value to the 100 Brinell point and increasing the constant multiplier accordingly, greater relative unit wear resistance may be attributed to the harder portions of the case. This is illustrated in Fig. 7 where the wear resistance at 100 Brinell is about half that of Fig. 6 and where the constant multiplier is very slightly over 1.47. The ratio of B/A is lower than under any of the other assumptions, and is shown on Fig. 5.

We conclude tentatively, however, that until we accumulate more service data on the wear resistance of the nitrided case, the logarith-

mic merit index offers us the most convenient method for comparing the wear resistance expectations of various *ductile* nitrided cases.

We also conclude that this logarithmic merit index is enough closer to the truth than the plain index and enough simpler than the geometric index to warrant its serious consideration for general adoption. (If a special coordinate paper is developed, the logarithmic scale loses the argument of relative simplicity.)

Analysis of Fig. 4

The analysis of Fig. 4 emphasizes some interesting facts with which we are already acquainted.

1. With zero case depth we have a zero merit index.

This of course is not a literal fact. What it means is that if the nitriding treatment adds no hard case, the gain to offset the cost of the material and treatment is zero.

2. From the standpoint of wear resistance alone (neglecting crushing due to possible excessive local pressure) a shallow case of 1000 Brinell is just as good as a deep case of equal hardness, provided the hard case is deeper than the condemning wear tolerance. We know of commercial production where excessive time of treatment is employed to secure an average depth of case more than ten times the depth of the condemning wear tolerance. The only logical reason for this is found in the unexplained variation of case depth which is occasionally encountered. Since long treatments tend to produce more spalling tendency than shorter treatments, the gain is somewhat doubtful. The demand for rapid and reliable commercial inspection methods is obvious. (See Appendix No. 2 for further analysis of merit index graphs.)

Practical Determination of Merit Index

The determination of a reliable merit index for a given steel and treatment is a very laborious procedure. To begin with, a reasonably consistent product is essential before a reliable index can be derived. Then it is very essential to realize that the index cannot be worked out properly from the exploration of one or two specimens. To mean anything worth while, it must be derived from the average of a number of specimens. We believe ten fairly consistent specimens, each taken from a different heat, is a rock bottom minimum number, and more specimens and heats are to be desired. Furthermore we

know that an index derived from the product of a given steel, and treatment in one nitriding plant, does not necessarily represent the product of other plants that are giving to the same steel a treatment which is supposed to be identical. This leads to the suggestion that before a plant has the right to use an index it should be derived from their own product.

In closing the discussion of the proposed merit index it is necessary to refer again to the fact that this index is based on hardness only. The service results to date seem to be rolling up quite a mass of data indicating that persistent spalling around the Vickers indentation indicates a case with an inferior wear resistance, regardless of, or perhaps we should say in spite of, hardness.

Our experience leads us to the conviction that a 900 Brinell case showing no spalling around the Vickers indentation will outwear a 1000 Brinell case where spalling does occur.

Evaluation of Ductility

We have groped after an evaluation of ductility which will be more quantitative than we now have. A slight approach to this may possibly be found in selective diamond indenters. It has been definitely proven that the Rockwell C diamond is not nearly as severe in spalling effect as the Vickers diamond. This is what we would expect since plastic flow is evenly distributed around a conical indenter, and is localized with a polygon pyramid indenter. It seems probable that a set of diamond points of increasing spall-producing tendency could be developed.

For example, starting with a sharp pointed cone as the least severe, planes tangent to the same cone could be cut to make 6-5-4 and 3 sided pyramids. The hardness evaluation need not be worked out for the various pyramids, they being used solely for determining the spalling limit of the case. It is greatly to be desired, however, that a less clumsy method for the quantitative evaluation of ductility be made available. Possibly the use of progressively increasing loads on the Vickers machine may give a very helpful indication of the degree of ductility. This looks to us worthy of sufficient research to establish the value of the procedure. The prime need today for evolving an ideal merit index for the nitrided case is a practical method for evaluating the degree of ductility of that part of the case that is to be worn away in service, but we need a merit index today

and in the absence of ductility evaluation we have made the best suggestion we could evolve. (See Appendix No. 3 for further discussion of ductility.)

CONCLUSIONS

1. Current reports of research on the hardness-depth characteristic of the nitrided case are plotted on random scales.

2. This hampers the rapid and critical comparison of the results of different reporters.

3. At this early stage of the nitriding development, it seems desirable and practical to develop a uniform method of reporting.

4. The suggestions in this paper are tentative and are for the purpose of starting discussion.

5. The American Society for Steel Treating Nitriding Committee is the logical body to develop a "Recommended Practice for Reporting on the Nitrided Case."

6. The depth-hardness characteristic seems to be a logical starting point for this Recommended Practice and other features may logically follow.

7. The depth-hardness characteristic as plotted on plain coordinates gives a misleading picture of the wear resistance of the case.

8. The use of a logarithmic scale of hardness and a plain scale of depth is suggested.

9. No defense is offered for the detail accuracy of the logarithmic scale for hardness.

10. A practical scale of greater proven accuracy would be welcomed.

11. In the appendix, the possible use of the scleroscope, as an inspection tool, is discussed.

12. A merit index for wear resistance is suggested.

13. This merit index is based on hardness alone and the utter necessity for some ductility of case is strongly emphasized.

Appendix No. 1—The Scleroscope

Attention is directed on the second page of the paper to the lack of a scleroscope-brinell conversion table which is applicable to the nitrided case. We doubt seriously whether it is possible to develop a conversion table which can be used with worth while reliability in the exploration of the hardness-depth characteristic of the nitrided

case. This doubt is based on the confusion of hardness and depth which we have found is exaggerated on thin cases to a much greater degree by the scleroscope than it is by the Vickers and than it would be with the Firth hardometer equipped with a 10-kilogram loading. But we are not at all certain that the scleroscope can be dismissed lightly from the whole nitriding development.

As a research tool for groping toward absolute hardness of the nitrided case (whatever that may mean) we are opposed to the scleroscope. But it would be foolish to close our eyes to the widespread use of the scleroscope, particularly in the smaller plants. It is only logical to expect this use to continue, and this fact imposes a research responsibility to define the proper scope of the scleroscope, and to calibrate its readings. It may be possible to capitalize the very confusion of hardness and depth which occurs with the scleroscope.

We have noted the practice of over-nitriding, to insure proper average hardness and depth. But it is well known that even when this practice is followed, some pieces fall below the acceptable minimum limits.

The file test is in commercial use in some plants as a 100 per cent test, i. e., each piece is tested for hardness with a file. This test is very unsatisfactory because:

1. One pass, with a new file over a 900 to 1000 Brinell case will dull the best file we have been able to find to such an extent that on a second pass the same spot on the file will fail to cut on a case some hundreds Brinell below 1000.

2. The best file will fail to touch a case 900 to 1000 Brinell hard and only say 0.001 inch thick.

It may be possible for a thorough research to calibrate the scleroscope sufficiently closely to make it possible to catch defective cases on say piston pins and similar parts where a shallow, hard case is all that the service requires. The suggested research may broaden the use of the scleroscope as an inspection tool, beyond the random illustration noted. We believe such a research is well worth while.

Appendix No. 2—Exploration of Case for Very Small Wear Tolerance

When the nitrided case is being explored for applications where the wear tolerance is very small, the customary taper grinding if

used, must be handled with unusual care. In looking over the literature for graphs of hardness-depth characteristic to illustrate this point, we have selected Fig. 23, on page 159 of A.S.S.T. TRANSACTIONS for Oct. 1929.

We must make it perfectly clear that we are using this Fig. for a purpose entirely different from that in Mr. Sergeson's mind.

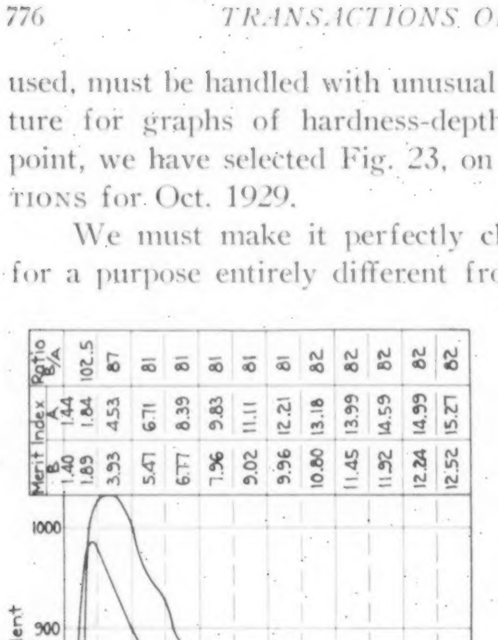


Fig. 8—Logarithmic Hardness-Depth Characteristic. TRANSACTIONS, A. S. S. T., Oct. 1929, Fig. 23, Page 159.

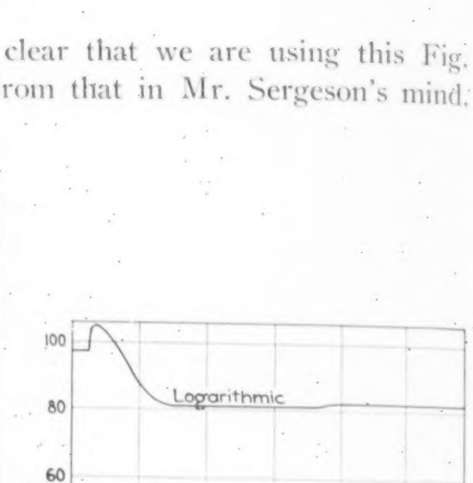


Fig. 9—Ratio $\frac{\text{Merit Index—3305}}{\text{Merit Index—3502}}$

Therefore there can be no thought on the part of anyone that criticism is implied in what follows. It simply happens that two of the characteristic curves in this Fig. form the best illustration we found of the point we wish to emphasize.

The two curves in question are replotted with the proposed logarithmic-hardness scale, in Fig. 8. (In this graph we have used the logarithmic scale in the range above 1000 Brinell.) We will assume that a selection is to be made between these two steels for parts which will be burnished after nitriding and which will go into a service where the condemning wear tolerance is 0.001 inch.

Fig. 9 shows the ratio $\frac{\text{merit index 3305}}{\text{merit index 3502}}$. This means that where the curve falls below 100 per cent 3502 is superior and where the curve lies above 100 per cent 3305 is superior. We will assume

first that the depth-hardness characteristics of Fig. 8 are entirely accurate. Then if the outer surface is simply burnished with practically no removal of metal or, say, a removal of 0.0001 inch, we see that steel 3502 is slightly superior. But if 0.001 inch is removed by grinding 3305 is the better product. We see very clearly that grinding off of at least 0.0015 inch is quite essential for securing the best service resident in steel 3305, while 0.0025 should be removed from steel 3502. If this is done then there is no question but what 3502 is the steel which will give the longest service (assuming equal ductility).

Coming now to a closer scrutiny of the hardness-depth characteristics as plotted in Fig. 8, we must realize that at the upper end of a taper ground surface it is extraordinarily difficult to determine just where the flat ends and the taper begins.

We believe that the exploration of the nitrided case, for the small wear limit we are discussing, should be prosecuted by successive flat grinding rather than by taper grinding. It is also essential in this class of investigation to remember that when the outer nitrided layer is softer than underlying layers, the Vickers, Firth and scleroscope, and in lesser degree, the Herbert pendulum credit the outer skin with higher hardness than it actually possesses.

Appendix No. 3—Straightening vs. Case Ductility

We have emphasized the need for means of checking up the degree of ductility of the nitrided case. It is very important that any tests made with the aim of learning something about case ductility shall indicate truly the point which they are intended to prove. There exists a rather serious misapprehension in connection with one operation which some observers believe indicates case ductility, and it is essential to call attention to the error in this assumption.

The statement has been published that if a part can be straightened after nitriding without cracking the case, this proves that a certain amount of ductility is present in the case. We offer the following demonstration for the statement that it is entirely possible to straighten nitrided parts where small distortion has occurred even though the outer layers of the case possess absolutely zero ductility.

Fig. 10 shows the load and support points for the straightening operation. Axial intercepts between the lines CD and AB indicate tension and compression stresses set up under the maximum de-

flection incurred during the straightening operation. Axial intercepts between the line CD and the line EFGHJK indicate the true proportional limit of the material at all radial locations. We know only by inference that the hard outer layers of the nitrided case possess a very high proportional limit. This, however, is a logical

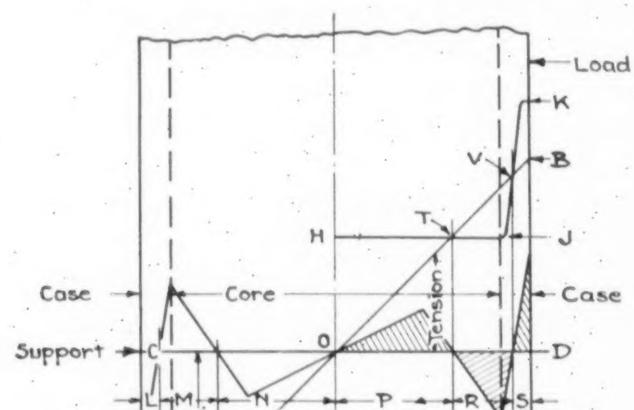


Fig. 10—Straightening vs. Case Ductility.

inference and is the basis of our statement regarding the straightening of a nitrided piece with absolutely brittle surface layers.

We are attempting no quantitative analysis since we have no information on modulus of elasticity and the other physical characteristics of the surface layers of a hard nitrided case.

Analyzing the tension, or right hand side of Fig. 10, we see that under the maximum straightening load, the material in the range P responds to the straightening load on its pure elastic characteristic because the stresses set up are below the proportional limit. Over the range R, the proportional limit of the material is exceeded, and therefore plastic flow occurs in this range during the straightening operation. Over the range S the action is again elastic because the material is stressed below its proportional limit. As always occurs in straightening operations, where combined elastic and plastic flow occur, the part must be bent beyond the straight condition by

an amount sufficient to leave it straight after the recovery which accompanies the removal of the external bending forces.

As the bending load is released, the range S in Fig. 10 undergoes a release of tension. This release however does not extend to zero except at the neutral line V and residual tension force exists. The same is true of the region P in Fig. 10. In the region R, however, where plastic flow has occurred, the tension stress will be reduced to zero and will pass through zero into residual compression. The shaded areas of Fig. 10 show a general indication of the distribution of the residual tension and compression stresses.

Then when the external bending forces have reached zero, the moment of the residual tension forces in the regions S and P must equal the moment of the residual compression forces in the region R, this being the condition of equilibrium. Of course if the case is ductile, then a greater degree of straightening can be effected without cracking the case than is possible when the case lacks all ductility, but some small degree of straightening can be effected with ductility entirely lacking in the outer layers of the case. Therefore the mere fact that a nitrided piece can be straightened, without cracking the case surface, sheds no light at all on the question whether ductility is present or absent in the case surface.

The only way that we know of to prove the existence of case surface ductility by means of a bending operation, is to use thin specimens which are nitrided with a hard case clear through the body of the specimen. We have tried this in a rather crude manner on strips of about 0.020 inch thick where the Vickers indentation indicated ductility, but we failed to find any permanent set as a result of bending. We believe, however, that with very accurate measuring devices some permanent set would have been detected.

Fig. 10 brings out very clearly a possible danger attendant upon the operation of straightening nitrided parts. In the narrow range from J to V, plastic flow under the influence of tension dies down from a maximum at J to zero at V. Corresponding compression phenomena occur from F to X. These actions are inevitably accompanied by heavy shear stresses in the region of the junction between the case and the core. If there is any inadequacy in this critical junction, it is entirely possible for the straightening operation to start a buried incipient rupture, which cannot be detected by any ordinary inspection method. This may then be developed by service and result in a spalling off of pieces of practically total case thick-

ness. The steel or the nitriding treatment may then be blamed for a service failure which is properly chargeable to the straightening operation.

For services where the corrosion resistance of the nitrided surface is highly important, there is a further undesirable tendency resulting from the straightening operation. We see from the shaded areas of Fig. 10 that there is a high local residual stress at the surface

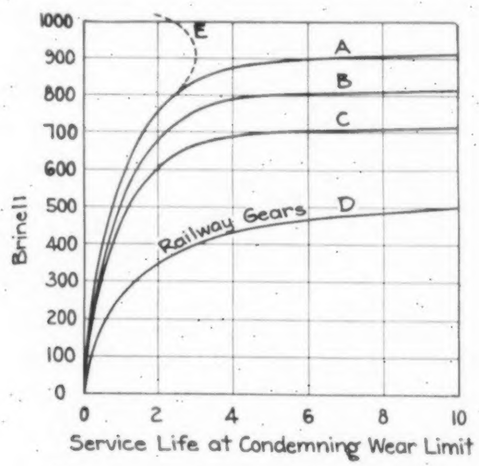


Fig. 11—Hardness vs. Wearing Life.

of the piece. McAdam has proven very conclusively that in the steels he studied corrosion attacks stressed regions much more actively than it does regions free from stress. Until the contrary is proven it appears logical to infer that parts which have been straightened after nitriding will have a lowered corrosion resistance in the surface areas which harbor residual stress.

We have serious doubt of the propriety of carrying out straightening operations on a large number of nitrided parts for vital and drastic service until success is pretty definitely proven by following, through a satisfactory life, a reasonable number of such parts in their specific service. Incidentally it is usually feasible by proper design and stress relieving pretreatment to forestall the need for straightening, and this is the safe and economic practice.

Appendix No. 4—Hardness versus Wear Resistance

While we know very little about wear phenomena, we can grope toward a visualization of the influence of hardness on wear resistance. In Fig. 11 we show a family of hypothetical curves and one actual service result which illustrate the fact that for a given

service there is some degree of hardness which will give a satisfactory wear resistance (assuming proper ductility). We assume that the service demands the scrapping of the part at some fixed wear limit. Each curve represents a different service. We will first justify the general shape of these curves.

The vertical co-ordinate is Brinell hardness and the horizontal co-ordinate is the length of time in service required to wear the part down to the condemning limit. The curve D, Fig. 11, represents the actual average service performance of certain classes of railway gears. The life scale for curve D is expressed in years.

We know from tens of thousands of gears in this service that a gear 500 Brinell hard will run for about ten years, while the life of a gear 350 Brinell hard in this service in only about two years. We also know that this curve must pass through zero. From these three points we therefore approximate the curve. As far as the general shape is concerned, the curve D is quite representative, and is all the justification we need for the general shape of curves A, B and C. For these latter curves, however, the horizontal scale must be regarded as time in the abstract rather than on the specific scale employed for purpose of practical illustration in connection with curve D.

Examining the most severe service illustrated, which is represented by curve A, we find that in this as in all other services with zero hardness, we will have zero life, which of course is obvious. Trying a material which is 100 Brinell hard we meet immediate failure.

As we step to higher Brinell values the life grows, but the growth is very slow until we enter the range of hardness of nitrided steel. At 800 Brinell we have 12 times the life we found at 200 Brinell, but the life is still unsatisfactory. At 900 Brinell, however, we rather suddenly enter the range of satisfactory life.

The other two curves of Fig. A show services where success is attained by 800 and 700 Brinell respectively. This substantiates our statement that wear resistance is not a direct and straight line function of hardness. It also shows us that there is no absolute scale by which we may define the wear resistance of the nitrided case as sharply as we can state its hardness. We are forced to the conclusion that the best we can hope for is some approach toward the relative wear resistance of various nitrided cases.

These curves are of course based upon the assumption that,

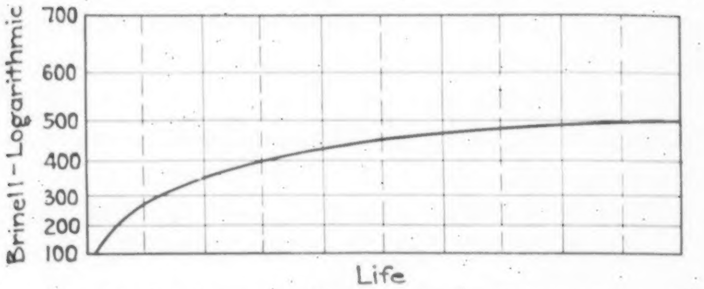


Fig. 12—Hardness-Life Characteristic of Railway Gears.

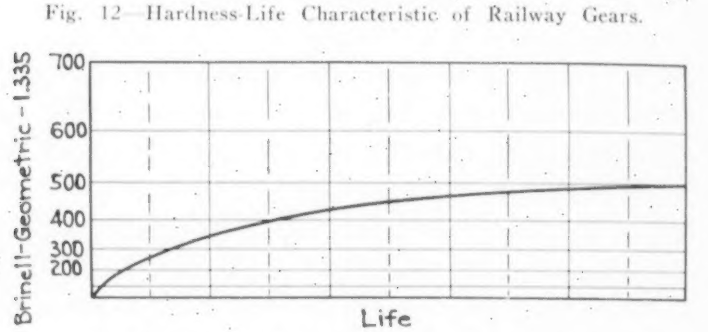


Fig. 13—Hardness-Life Characteristic Railway Gears.

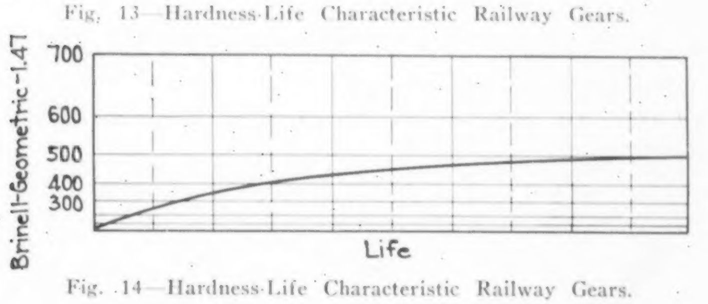


Fig. 14—Hardness-Life Characteristic Railway Gears.

as the hardness increases, the material retains a degree of ductility which is sufficient to permit the capitalization of the hardness in terms of wear resistance. We do not know very closely what this essential degree of ductility is. But it is interesting to see what tendency creeps in when the ductility becomes increasingly inadequate as the hardness reaches apparently desirable values. This is illustrated by the dotted line E, Fig. 11, which departs from the full line A at its knee. We see that a maximum service life is achieved at 920 Brinell. With further increase of hardness the length of service decreases. We are entering now a very indeterminate range. If we draw an inference from the diamond, we might conclude that the curve would ultimately change its direction to the right and become asymptotic at infinite hardness.

It is not profitable to pursue this imaginary condition further than to note that we are probably dealing with a granular structure

and that there is ground for the belief that in arriving via the nitriding treatment at some degree of hardness probably peculiar to each combination of steel and treatment, there is an attack on the structure of the steel either granular or intergranular or both, which starts to deteriorate the case as a mechanical structure.

From Fig. 11 we can derive a method which may be used eventually in checking up the accuracy of the logarithmic or other progressive scale of hardness.

Figs. 12, 13 and 14 are replots of curve D, Fig. 11, on the progressive hardness scales of Figs. 3, 6 and 7, respectively. The departure of the resulting curve from a straight line is a measure of the error in the progressive scales of these three Figs. for the particular gear application shown in curve D, Fig. 11.

We find a material discrepancy in Fig. 12 and a smaller error in Fig. 13 while in Fig. 14 we have a closer approximation to actual service results although in this rather low range of hardness the progression of the hardness scale is too slow even in Fig. 14.

The practical application of this method lies in the gradual accumulation of service life data for nitrided parts, and from this data the deviation by the suggested method of the particular progressive hardness scale which most closely approximates the truth, as shown by plotting in a straight line.

RECENT DEVELOPMENTS IN NORMALIZING SHEET STEEL

By Edward S. Lawrence

Abstract

This article discusses, in general and chronological order, the major mechanical, mechanical-metallurgical and metallurgical improvements of the continuous sheet normalizing furnace.

It brings forth, in concise statements, the advent of the continuous sheet normalizer and the necessity for improvements over prior art furnaces.

The major metallurgical improvements center themselves around a correctly constructed cooling chamber wherein the time and rate of cooling the sheets is emphasized.

Introduction

THE chronological mechanical and metallurgical developments, involved in the so-called continuous normalizing of thin-gaged, low carbon, deep drawing sheet steel, are, without doubt, worthy of recording and recognition. This heat treating process has revolutionized the art of producing severely drawn sheet stampings with a minimum amount of breakage together with the maximum of smooth surface.

This process of normalizing necessitates heating the steel to a point above its upper critical temperature range within and slightly above which range, the original grain structure becomes obliterated and a new and extremely fine structure is originated. This grain structure, in turn, is retained or allowed to grow slightly depending on the time and rate of cooling.

Five years ago this particular heat treatment for low carbon sheet steel was still confined to text books and possibly a few laboratory experiments. Certainly, no commercial furnaces were available at that time to produce practically this extremely fine-grained sheet.

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To be sure it will be said that five years ago there were continuous blue annealing sheet furnaces but it will be conclusively shown that these furnaces were quite inadequate for normalizing in spite of the fact that they were the forerunner of the present day continuous sheet normalizing furnaces.

Reasons for Normalizing

The development of continuous sheet normalizing can, in all probability, be attributed to the large potential demand for automobiles at lower prices. Mass production would satisfy this potential demand but was controlled, in large part, by the steel furnished by the sheet and strip makers.

The steel used several years ago for automobile bodies, fenders and the like was the regular double box-annealed sheet. This sheet possessed inferior properties such as drawability, surface, and a considerable percentage of it failed in the presses particularly when efforts were made to enlarge and speed up the presses. Strip mills attempted to obtain part of the tonnage previously supplied by the sheet manufacturers but this strip material was subjected to the same double box annealing process as that used by the sheet makers and was no more successful than the sheet material had been because its properties were substantially those of the sheet material. Mass production of automobiles at lower prices was thus controlled, to a large extent, by the ability of the sheet and strip makers to produce steel having improved properties which would permit larger presses to be used, the speeding up of the presses, the deep drawing of the steel which would make it possible to form from a single piece of steel parts previously made from two or more pieces of steel, and to furnish steel with such properties that the surface could be painted with less time and material than had previously been possible with sheets which had poor surfaces or tended to crack when drawn.

This problem of mass production of automobiles has been solved by the development of the continuous sheet normalizing furnace and methods. It, as previously stated, revolutionized the stamping of deep drawing automobile body sheets and presented quality and surface never heretofore practically possible. It satisfied a demand for normalized sheets to the extent of 80 to 85 per cent of all automobile body sheet produced up to this time, and has seemingly satisfied the demands of sheet consumers so far as quality is concerned.

Momentarily, it has held its own with strip-sheet producers but this is probably short-lived as strip producers are fast accepting continuous normalizing thus successfully tying it in with their continuous methods of hot rolling, pickling and cold rolling.

Advent of the Normalizer

As previously mentioned, the first steps taken in developing our present sheet normalizers was to utilize existing continuous sheet heating furnaces. Naturally, attention was first drawn to the continuous blue annealing sheet furnaces then in extensive use. The majority of these furnaces were between thirty and fifty feet in length and of sufficient width to allow the widest sheet to travel length-wise through it. The sheets travelled in a horizontal position supported either on fingers or lugs attached to a chain which, in turn, ran in a slotted hearth, or they were supported on cast iron disks mounted on water-cooled steel tubing extending transversely across the furnace and supported in bearings on the outside.

These blue annealing furnaces were operated so as to heat the low carbon sheet to a temperature about half way between its lower and upper critical temperature range or approximately 1400 degrees Fahr. with a possible slightly higher temperature for very low carbon sheets. The purpose of this was to not only relieve hot mill strain and equiax the distorted grains but also to introduce sufficient heat to the mass so that in the presence of steam its surface could be given a uniform coating of blue oxide.

To normalize instead of anneal, the furnace temperatures were raised several hundred degrees in order to induce into the sheet a temperature exceeding its upper critical range which practically was over 1700 degrees Fahr. Naturally, this began to complicate matters.

From a mechanical standpoint the water-cooled shafts conveyed away a tremendous amount of heat, the cast iron disks failed miserably, the side walls bulged thus cramping the shafts, bearings became overheated thus causing wheels to cease rotating and thus scratch the sheets, bricks spalled and spoiled the surface of the normalized sheets, the conveying wheels or fingers pitted and scratched the underside of the sheets and caused their final rejection while excessive scaling of the sheet took place as it was discharged from the furnace into the open air. Nonuniformity of grain structure existed as those portions of the sheet which traveled over cold disks

or on cool fingers prohibited the refinement of grain that existed where the sheet made no contact with this cold conveying mechanism. Furthermore, only one sheet could be practically conveyed at a time because piling two or more sheets into pack form gave very nonuniform heat distribution. Added to this was a poor control of the firing of fuel with "cold spots" or sections existing within the furnace. The conveying mechanism for the most part was spaced too far apart and the thin gage, dead soft sheets had a habit of dropping onto the hearth or doubling up, thus causing serious jams that necessitated shutting down the furnace and tearing out the side walls to allow repairs or replacements.

These are but the major mechanical difficulties encountered when continuous blue annealing furnaces were drafted for a use to which they could never be adaptable. They form a sharp contrast to our present day continuous sheet normalizers but the surmounting of these mechanical obstacles form but a part of this paper.

Mechanical Improvements

The first move made to improve and adapt these blue annealing furnaces to normalizing conditions was to substitute heat resisting alloy fingers or disks for the cast iron, bring the conveying mechanism closer together and in the case of roller disks, staggering the disks on every other shaft so that a slight overlapping prevented to a greater extent the possibility of sheets dropping to the hearth especially in the hottest section of the furnace which was next to the discharging door.

A better grade of heat resisting and insulating brick was used for the crown, roof and side walls which aided in the retaining of heat and allowed less spalling of the brick.

One of the most recent developments to prevent bulging side walls and the cramping of the mechanism, is to build these long heating chambers in sections, each section being about five feet in length. These sections comprise a cast steel frame which holds the insulating asbestos and brick. The sections are then set on the lower side walls so that in the case of roller type mechanism, half of the shaft is in the lower side wall and the other half in this upper sectional frame. These sections are cemented together to prevent heat losses and gas leakage. As the furnaces heat up to a temperature close to 2000 degrees Fahr. the furnace walls expand sectionally and

principally in a longitudinal direction thus preventing bulging which so often occurs in solidly built furnace walls where the expansion multiplies very rapidly. Another advantage to this sectional type is that it permits ready access to the conveying mechanism for the removal of defective shafts or disks, the cleaning out of scale which gradually accumulates on the hearth and prevents a loss of time which can readily be imagined if these repairs had to be made on a solid wall furnace which must be cooled to a temperature which allows men to tear out the side walls or to work within. For some normalizers using roller mechanism the bearings are underslung which means tearing out bottom side walls below the conveyor shafts only. While this method has its advantages, it presents more lost motion and time than is evident for the sectional furnace. Further improvements to the heating chamber have come about through the insulating of the hearth. Insulated furnace hearths are not new in themselves but to apply it to this specific type of furnace it has presented a new and novel feature which has meant a great deal more to sheet producers than we might at first suppose.

For example, the earlier type of sheet normalizer was not insulated; it was not necessary. Sheets, for instance, travelling over water-cooled mechanism allowed very little heat to get to the floor of the furnace. Gradually, it was found that from a metallurgical standpoint the sheet was getting a nonuniform structure and insulated or non-water cooled conveying mechanism was introduced both of which are of prime importance. However, while an insulated and non-water cooled conveying mechanism prevented to a great extent this nonuniformity of structure the heat which was now able to penetrate to a point below the conveying mechanism was being carried away very rapidly through a non-insulated hearth, thus causing a wide range of temperatures to exist above and below the improved mechanism.

To overcome this mechanical defect the hearths were insulated and with the continued use of insulated and non-water cooled shafts the temperatures above and below the conveying mechanism more closely approached each other. This development has meant a great deal because without it, we could not have graduated from the narrow continuous normalizers approximately 60 inches in width to our present types ranging from 72 to 108 inches in hearth width. Nor was this development made any too soon because as sheets were

demanded and rolled more and more in the wider widths these insulated hearth normalizing furnaces were transversely expanded to handle sheets of any width and length as rolled on the hot mills today.

Naturally, with the advent of conveyor mechanism such as rotating disks mounted on insulated and non-water cooled sheaths it was possible to overcome such disadvantages previously mentioned as overheated bearings, water-cooled shafts, and scratched sheets from non-rotating shafts. With respect to this latter mentioned improvement, this has been aided by improved bevel gear drives and the utilizing of continuous chain.

While discussing insulated sheath type shafts, it might be added that a great deal of trouble did and still is existing in that the insulation often leaked out. However, insulated shafts are now available, the manufacturers of which state that insulation leakage is impossible. Depending on the fuel available not all users of continuous sheet normalizers can install non-water cooled shafts. The majority of such furnaces, however, are dependent upon the insulated type of shaft.

Mechanical-Metallurgical Improvements

In a mechanical sense the major portion of the difficulties having been overcome as described, another class presents itself which is really neither a mechanical nor metallurgical improvement but which influences both and has proven to be worthy of recognition as a factor contributing to the improved sheet normalizer. The first and foremost factor is the prevention of scale accumulating on the hearth of the furnace. This scale comes from the steel carrier sheet which separates the sheets being normalized from the conveying mechanism. Originally, the rough scaly spots on the mechanism caused a pitting of the good sheet with which it came in contact. This was overcome by using the steel carrier which is a discarded waster sheet from the warehouse. These carriers scaled badly in their repeated trips through the furnace. The scale gradually accumulated on the hearth to the extent that the conveying mechanism often was running in it, necessitating occasional shut downs of the furnace in order that the scale might be cleaned out. This was a slow and tedious job to say nothing of the loss of time. Scaly sheets aggravated the adherence of scale to the conveyor mechanism and once resorted to as a means of keeping sheets from pitting, it could not be abandoned. The use

of carriers necessitated more labor for their handling at each end of the furnace and unnecessary high heat losses.

These are mainly mechanical features but they tie in with the metallurgical features in that a hearth covered with scale has often prevented the correct circulation of gases and heat to the underside of the material thus preventing uniformity of the anneal. To offset this, additional heat was introduced which caused overannealing particularly if two or more sheets were being normalized in pack form, the top sheet thus receiving more heat and ultimately not having the same structure as the bottom sheet. Raising the temperature to overcome the presence of a scaly hearth not only affected the physical structure of the material but incidentally raised the temperature of the furnace which has its disadvantages at these high furnace temperatures for normalizing.

In order to temporarily get away from scaly steel sheets, certain alloy companies have introduced chromium and chromium-nickel sheets of thin gage to supplant this scaly steel carrier sheet. These sheets of chromium-nickel not only outlast the steel carrier but there is no scaling and the uniformity of heating is maintained. Chromium-nickel sheets show a tendency not only to evenly absorb and dissipate this heat very rapidly but by its evenness of absorption and dissipation, the sheets which they carry are more evenly heated and cooled. In contrast, if the sheets to be normalized were conveyed on badly scaled steel sheets, they would show varying heat transfers depending on the amount of scale. While it may seem that one is "splitting hairs" on this discussion this point means a great deal to the full-finished sheet maker who must present a uniformly heat treated sheet if it is to make the difficult stampings that are demanded today.

At the present time steps are being taken that will eventually eliminate the use of the carrier sheet by introducing means by which the conveyor mechanism is kept free of scale. These means are slowly and successfully being accomplished but in the meantime, the thin chromium-nickel carrier sheet is showing results that will necessitate a drastic change entirely to eliminate its use.

Metallurgical Improvements

From a metallurgical standpoint, the majority of improvements in a continuous sheet normalizer have taken place after the sheets

have reached their normalizing temperature range which occurs in the heating chamber. This heating cycle within the heating chamber or zone has remained practically unchanged as the sheet temperature ranges and the rate of heat absorption depend largely on the carbon content and the gage and size of the sheets respectively all of which are commercially within close limits.

Thus, from a metallurgist's viewpoint, the heating cycle is well and practically established and if it failed, it was due to mechanical difficulties which have just been described. This statement is, of course, made with due allowances for a slight soaking period which exists in the heating cycle of any continuous sheet normalizer. This has not been discussed as it is a variable which depends on hot mill practice and, furthermore, upon the construction and operation of the furnace. A soaking period tends to more evenly normalize and for this reason, it is a constant factor in our discussion. Having shown that mechanical engineers have partially overcome these objectionable mechanical features, let us assume for the moment that the correct heating cycle maintained in a mechanically correct heating chamber is also a constant factor.

This leaves only the cooling cycle in which to show our metallurgical improvements but this is indeed sufficient because the major improvements of this nature have been found to depend largely on the time, rate and manner of cooling of the sheets. The discussion of the cooling cycle involved in low carbon deep drawing sheets as heat treated in a continuous furnace presents sufficient problems and solutions that warrant more time and attention than this paper could adequately detail or describe.

It is sufficient, however, for the sake of clearness and simplicity to describe briefly the more or less chronological metallurgical developments growing out of this cooling cycle and to note the effect they have had on the resultant sheets.

Advent of a Cooling Zone

The sheet normalizers, in the beginning and for some little time, carried no cooling zones. The sheets after reaching their normalizing temperatures, were discharged from the heating chamber into the open air at sheet temperature ranging from 1550 to 1800 degrees Fahr. As it has been stated, these sheets scaled very badly but it was considered a necessary evil in view of the fact that the quick

chill or cooling of the sheet was necessary to set or hold the fine grain structure characteristic of this particular heat treatment. While the sheet became quite stiff under this rapid cooling its subsequent processing usually involved a box annealing at low temperatures which showed a tendency to relieve some of this stiffness and hardness imparted to it.

However, the scaling became so objectionable from the standpoint of pickling losses and poor surface that makeshift covers were placed over a short portion of the runout or cooling tables. These covers prevented to some extent, the harsh scaling but sufficient air was present to prevent absolute freedom of scaling so far as free oxygen was concerned. The rapid chilling of the metal went on unmolested.

These make-shift covers were incapable of materially improving the metallurgical characteristics of the metal and were used but very little and quickly discarded as useless from a metallurgical standpoint. This point in the development marks the beginning of the advance metallurgical improvements. When the possibilities and true functions of cooling chambers were discovered, these improvements were obtained for the first time. Some of the structural features of the cooling chambers which enter into and affect the metallurgical changes are as follows:

The wall which divided the heating chamber from this cooling chamber or zone was of sufficient restriction to cause a sufficient lowering of sheet temperature so that the fine grain structure was retained, and, therefore, it was found that the necessity of discharging into the open air could be avoided. Some furnaces installed restricted passages which were elevatable and adjustable and thus controlled the amount of heat and products of combustion that might pass from the heating into the cooling chambers.

For the most part, commercial furnaces of the type being described carried cooling zones whose cross sectional area equalled the cross sectional area of the heating chamber and while they prevented to some extent the presence of free air or oxygen, it was not uncommon for air to suck back into the cooling chambers thus occasionally raising an objectionable scale. This short period of cooling under a cooling zone prevented the extreme stiffening action as noted on prior furnaces and this slightly increased softness meant less time consumed in the subsequent low temperature box anneal.

From a metallurgist's standpoint, this can be explained in that the majority of this stiffness is due to the particular structure of the iron carbide. The carbon of the sheet in the form of cementite combines with a fixed amount of ferrite or iron grains to form pearlite. Depending on the rapidity of cooling from normalizing to room temperatures, this pearlite can assume various allotropic forms and in the case of the quick cool, would be emulsified or what is known as sorbite or sorbitic pearlite. Now, if the cooling of this sheet could be retarded somewhat after the crystals had been fixed, the sorbitic form could be changed to a more or less semi-laminated condition wherein the cementite and ferrite within the pearlite grains would separate into layers. This form presents a softer state of pearlite. As ferrite grains in themselves as formed under these conditions are relatively soft, this, together with a softer or semi-laminated pearlite present a resultant softer sheet. This metallurgical change is one of the reasons for box-annealed sheets having such a high degree of softness because the cooling within the box for a prolonged period has brought about this semi-laminated condition of pearlite.

With this in mind, the cooling zones of continuous sheet normalizers have been repeatedly changed in kaleidoscopic rapidity in order to foster this slow cooling. It must be said at this time, however, that a fine-grained sheet will never commercially approach the softness of box-annealed sheets only for the more grains per given area add to its rigidity. However, as this discussion proceeds, the possibility of eliminating the subsequent box anneal necessary for most normalized sheets at the present time, will become more evident and possible.

At first, these short cooling zones employed burners to retard the rapid cooling of the metal and if this was not resorted to, steps were taken to discharge from the cooling zone at a temperature just below the non-scaling range and thence to pile at a red heat to bring about this softening action. This method has certainly aided in softening the sheets but the cooling has not been uniform for outer portions of the pack first to cool carried the small normalized grain while the center portions of the pack last to cool, showed slight grain growth. This unevenness in grain size throughout the sheet has a noticeable effect when the sheet is being drawn to shape under the presses.

To overcome this undesirable feature, the sheets were caused

to travel through the cooling chamber surrounded by waste gases and products of combustion from the heating chamber. This was accomplished by lowering the roof of the cooling chamber as close to the sheets as practically possible. This change not only further reduced the scaling, but it more uniformly retarded the rate of cooling and allowed the desired softening action.

Thus, the sheets are chilled sufficiently as they pass under the restricted passage to retain the grain size desired and if from that point on, the cooling is uniformly retarded, the result is that a relatively soft sheet is finally obtained. By increasing the length of this cooling chamber, the residual heat of the sheet can be utilized just as is done in the box anneal and the longer the cooling chamber the closer is the approach to the commercial range of softness desired for this grade of steel. The time and the rate at which this steel is cooled is dependent on many factors such as, the carbon content, type of grain and size of grain. It is however, sufficient to say that these factors can be regulated very nicely where the cooling rate is allowed uniformly to progress undisturbed under a cooling chamber of the correct construction.

With these features in mind, the construction of a continuous sheet normalizer at the present time is to increase and properly to erect a cooling chamber so that the discharged sheet has shown a uniform cool and that the ultimate in softening action has taken place. In this manner, the residual heat in the sheet is utilized to bring about a softening action without appreciably disturbing the grain structure attained as the sheets passed under the restricted passage.

Not only have furnace lengths been scrutinized but the conveyor mechanism in the up-to-date cooling zone has been so constructed that no secondary chilling action of the sheet is allowed to take place. In this respect, attention is called to earlier types of normalizers, the majority of whose cooling chamber utilized conveyor disks mounted directly on water-cooled steel tubing. While it is necessary to dissipate heat fairly rapidly it is essential that it be done in a uniform manner and late designs include insulated shafts under the cooling zone. For the most part, insulated alloy shafts occupy that portion of the cooling zone where the sheet is at a scaling temperature, the next step being the conveying on insulated semi-steel shafts and finally, on non-insulated steel shafts. The insulated semi-steel

shafts prevent a secondary chilling as previously described and which chilling should be avoided.

Thus, the time and rate of cooling has brought about a uniformity of grain which, in turn, allows not only evenness of drawing properties but this uniformly retarded cooling has softened the sheet. As the present time, the usual processing of full-finished automobile body sheet involves a low temperature box anneal after normalizing in order to somewhat reduce the stiffness set up by this normalizing treatment. At this very moment, a more careful study of cooling zone conditions are allowing a great many grades of normalized sheets to be shipped to the customer directly after this heat treatment because the cooling cycle has been so regulated that the sheet has sufficient softness to do the work demanded of the material. If this subsequent box anneal is necessary, it necessitates a low temperature soak, the time of the soak being in fairly good proportion to the length of the cooling chamber.

By that statement it is meant that the normalized sheets cooled under a long cooling zone require only a short time, low temperature soak in its subsequent box anneal, whereas normalized sheets more quickly cooled under a short cooling zone require a longer time low temperature soak in its subsequent box annealing.

The day is not far distant when space will be allowed for a prolonged time and rate of cooling from the normalizing to the discharge temperatures so that the resultant sheet will, in the majority of cases, not require any subsequent box anneal whatsoever.

DISCUSSION

A. L. Davis[1]: I am not a sheet steel man, but I am interested in this question of continuous handling of metals and annealing. I am wondering whether Mr. Lawrence could give us some idea of the time cycle. Of course we know how prolonged it is in the old box method. Also perhaps Mr. Lawrence could say something about temperature control, and the methods of obtaining it, in the continuous normalizing. In the brass industry we have always annealed in truck loads.

E. S. Lawrence: So far as continuous heat treating of brass in this type of furnace is concerned, I do not know of any such furnace at present commercially operated at a sufficiently low temperature for that particular grade of material. However, I believe it is possible to build a furnace of a continuous type to anneal brass at a low temperature. As far as fuel is concerned, the electrical means of heating probably present the best means of getting heat

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into the brass sheet. But that is a problem that has to be worked out. So far as putting your finger on the time cycle of continuous normalizing or heat treating steel sheets is concerned, that is hard to do. For the most part, to practically normalize a low carbon steel sheet we have to heat at 1700 degrees Fahr., which is not quite 100 degrees above the upper critical temperature range. We have to shorten or extend our soaking period according to the hot mill practice. In other words, some sheets are finished fairly hot and others fairly cold on the hot mills which of course induces different degrees of strain in the metal which must be relieved. We can normalize a sheet without relieving those strains. That brings in the factor of a soaking period. The average furnace with its average tonnage of around 140 to 150 tons to a 24-hour day would take around 5 minutes for the heating cycle.

With respect to temperature control the normalizing furnaces using gas average and carry either 2 or 3 automatic temperature control zones. There are a number of furnaces using oil, but it has not, thus far, been practical to put an automatic control on the oil-fired type of furnace. It depends largely on the operator who has from 40 to 60 burners to watch. Hand control is rather difficult on an oil furnace, but has proved to be the most satisfactory.

GLEN COLEY[2]: Mr. Lawrence mentioned that some work was being done with the removing of waste sheets. I wonder if he would tell us along what lines that work is being carried out.

E. S. LAWRENCE: I feel that in justice to the men who have developed this thing, that at the present time it is more or less of a personal question. Various means have been tried out. One of the most important means is to try conveyors of varying chemical compositions, nickel and chromium for instance, to see whether or not that effects pitting. In other words, will the scale on the steel carrier sheet stick more to a straight chromium carrier mechanism or to a high nickel piece of conveyor mechanism. There have been various means tried of keeping the conveyor disk clean, but in justice to the men who have developed them I am in no position now to divulge those means. I believe, however, that they will be brought to your attention shortly.

E. E. THUM[3]: Something might be said for the "antiquated" method of box annealing. Perhaps it may seem that I am standing on a strange platform, upholding something at least 400 years old, but you must remember that box annealing, being an intermittent method, is very well adapted to the rolling methods used in the manufacture of sheet and tin plate. In other words, sheet and tin plate is produced one piece at a time by a discontinuous process. What, therefore, should be more natural than that the various heat treatment processes should also be discontinuous? In fact, that is just exactly what box annealing is. When you introduce continuous heat treating processes, such as automatic normalizing furnaces, into an old fashioned sheet mill, you are putting something continuous in the midst of a number of discontinuous operations. The very best place for a continuous normalizing furnace would be in a continuous sheet or strip mill. However, most of the trouble connected with the

[2]Member A. S. S. T. Power Sales Dept., Detroit Edison Co., Detroit.

[3]Member A. S. S. T. Editorial Staff, *Iron Age*, New York City.

furnace, as Mr. Lawrence stated, has to do with the problem of handling small units through a long furnace. Would it not be a logical way to avoid those troubles to replace these units by a continuous piece? Twenty-five years ago that suggestion would have been out of place because we had no means of economically doing it, but at the present time we know how to connect the individual sheets into a long strip by welding, stapling, clamping, or riveting. When that is done and the joints are made with sufficient strength so that the sheets become a continuous strip capable of taking considerable strain, then you can handle the material through a furnace having far fewer rollers in the hearth, much in the same way as the narrower strip or wire is handled through a long furnace in the wire and spring industry.

This would be one means of getting around the mechanical handling devices which, at the present time, are expensive and which are bound to be expensive as long as nickel and chromium sells for a high figure.

E. S. LAWRENCE: Yes, Mr. Thum's last remark regarding high alloy costs is very good. One of the big troubles with normalizing furnaces is the high initial cost of the alloy. There is a tendency among furnace users to get away as much as possible from the high initial cost, the major part of which is absorbed in the alloy conveyor mechanism at the present time.

With regard to welding the sheets together to form a continuous strip I will say that at the present time the sheet industry is in a transition period as an outgrowth of the competition of the strip people who started the steel sheet people working more along increased lines of production. They first introduced a continuous furnace which not only sped up production and output, but at the same time produced a quality of sheet which satisfied the automobile people.

So far as the continuous furnace is concerned, we might state that it is entirely possible to fasten the sheets together but we question the ultimate cost in view of present success with continuous normalizing of single sheets. If you had a sheet that required box annealing, you could do it in a continuous furnace and get a uniformity of structure that would have been impossible in the box; furthermore, you could do in 3 hours what it would take 3 days to do in the box. A chance to cut 3 days off a production schedule is important.

With further reference to Mr. Thum's remarks regarding welding or otherwise assembling short sheets into continuous lengths for normalizing. The welding together of sheets to form this continuous strip, while possible, is costly both from the standpoint of lost time and loss of metal by subsequent trimming and would show no outstanding advantage where roller type normalizers are concerned. If one considers dragging the material through the furnace, then consideration of a full finished sheet possessing good surface must be eliminated from such a furnace. The majority of continuous normalizers in sheet mills today must utilize conveyor mechanism that not only contribute to the uniformity of heat treatment but to the surface of the sheet as well. In the light of the late developments in heat treating full finished sheets, I am of the opinion that no progressive sheet manufacturer using discontinuous methods of processing will honestly state that box annealing is the logical heat treatment for his product and that continuous normalizing or annealing furnaces are out of place in his present discontinuous processing equipment.

A STUDY OF THE QUENCHING OF STEELS

Part II

By H. J. French

Abstract

Part Two of this paper relates to some of the sources of variations in the quenching of steels and to comparisons of different coolants. Attention is given to the diffusivity of the metal, the oxidation and smoothness of the metal surfaces, the effects of gases dissolved or formed in the coolant, coolant circulation, and coolant temperatures.

The critical cooling rates and depth hardening properties of carbon steel are discussed and data given for the effects of carbon content and grain size in the McQuaid-Ehn carburizing test upon the heat treatment properties of steels.

In addition to considering the characteristics of water, commonly used aqueous solutions, oils and air, some data are given for special coolants, and a brief discussion is included of the magnitude of the differences between center and surface temperatures in the cooling of spheres in water, oil and air.

Chapter III

SOME OF THE SOURCES OF VARIATION IN THE QUENCHING OF STEELS

THE object of quenching is to provide certain definite properties in steels, whether the steels are used as quenched or subsequently tempered before being applied in service. From a practical viewpoint it is not enough to produce these properties once but the conditions must be chosen so that the desired results will be obtained repeatedly. Uniformity of results depends equally upon uniformity in heat treatment practice and uniformity in the metals under treatment.

Evidence was previously presented that the trend of cooling in some of the customary liquids was not only not uniform from point to point on the surface of steel pieces but was probably the resultant of rapid and repeated fluctuations in temperature, often over rather

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wide ranges. The practical significance of this is that there is small chance of securing a good degree of uniformity by simple immersion of heated steels in motionless or slow moving liquid coolants without due regard to the conditions obtaining in the liquids. Instead it would appear to be necessary to strive to provide the conditions which will promote uniformity.

It is not difficult to visualize how variations may be introduced from three main sources, (1) from the metal itself, (2) from the preparation of the metal for quenching (machining, heating for hardening, etc.) and (3) from the conditions of immersion in the coolant. These items can be subdivided further but this would serve no useful purpose since it was not practicable to study all of the variables from the several main sources.

1. Diffusivity

One of the properties of the metal itself which can be expected to affect the rate of heat loss is the diffusivity. This is defined as the thermal conductivity divided by the product of the specific heat and density.

The diffusivity of carbon steels at atmospheric temperatures[24] is in the range 0.10 to 0.17 $cm.^2 sec.^{-1}$. Providing no constitutional changes are involved, the diffusivity tends to decrease as the temperature increases and available data indicate that the differences in values for different steels tend to decrease.

From theoretical considerations a steel with high diffusivity may be expected to lose heat somewhat more rapidly at the center or other interior points of the body than a steel with low diffusivity but its surface should lose heat at about the same or a slower rate. In other words, metal of high diffusivity may be conceived to feed more quickly to the surface the heat which is in the interior and so tend to decrease the rate of temperature change at the surface.

As was indicated already, carbon steels of different carbon contents probably do not differ very widely in diffusivity at given temperatures. Copper has roughly ten times the diffusivity of carbon steels at atmospheric temperatures. While its surface conductivity differs from that of steels, comparison of the surface and center cooling curves of copper and steel spheres offers a means for developing the magnitude of the effects which may be expected.

[24]Landolt, Boernstein, Roth, Scheel, Physikalisch-Chemische Tabellen. 5. Auflage, Vol. II, p. 1309.

Table XIV

Effect of Surface Condition on the Cooling at the Surface of 1-inch Spheres Quenched in Water[1]

Condition of Surface when Quenched	Condition of Surface after Quench	Heated in Air 10 Minutes and Quenched
	Heavily Oxidized Samples	
Blued by heating 1 hr. at 750 degrees Fahr. (400 degrees Cent.) in 8-KNO_3, 1-MnO_2 (by weight)	Heavily oxidized but less pitting than with usual method.	Little difference
Held 1 hr. in open furnace at 1605 degrees Fahr. (875 degrees Cent.) before quenching	Heavily oxidized.	Little difference
	Surface Oxidation Minimized	
Heated in furnace containing sawdust	Cleaner than with usual method.	Slow, especially at 350 to 600 degrees Cent.
Heated in nitrogen	Cleaner than with usual method—less pitting—Adherent oxide.	
Heated in illuminating gas	Carbon deposit on samples; otherwise like samples heated in nitrogen.	Slow, possibly due to carbon deposit on surface
Heated in salt bath, equal parts by weight of $CaCl_2$ and $BaCl_2$	Very clean.	Rapid—like brine quenching
	Plated Specimens	
Nickel plated (approx. 0.001" coating)	Adherent scale.	Slow over entire temperature range.

[1]All samples quenched from 875 degrees Cent. (1605 degrees Fahr.) in water at 19-22 degrees Cent. and moving at 3 feet per second.

Fig. 55, representing the cooling curves of copper and steel spheres, 1½ inches in diameter, shows the very much more rapid cooling at the interior of the copper body. On the other hand, the surface of the copper sphere cooled more slowly than that of the steel sphere to temperatures in the neighborhood of 150 degrees Cent. (300 degrees Fahr.). The differences were not marked until temperatures around 500 degrees Cent. (930 degrees Fahr.) were reached when the surface of the copper sphere showed a marked increase in cooling times. Crossing of the surface curves at about 100 degrees Cent. (210 degrees Fahr.) may be ascribed in part to the heat of transformations in the steel.

The differences in diffusivity of commercial carbon and low alloy steels which are ordinarily hardened by water quenching are only a fraction of the differences between steels and copper. Therefore, variations in the cooling curves of such steels may be expected to be small in most cases. As will be shown later such differences are much less important than variations which may be introduced by the manner in which the quenching operation is carried out. However, an increase in diffusivity of the metal quenched should tend to in-

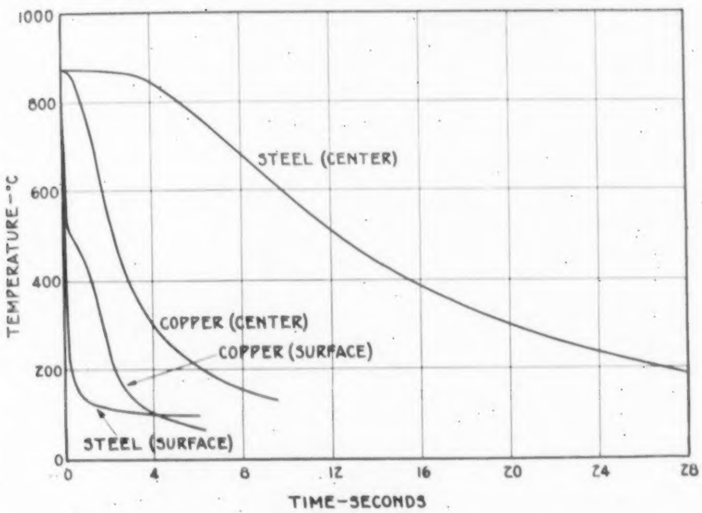

Fig. 55—Surface and Center Cooling Curves of Copper and Steel Spheres 1½ Inches in Diameter When Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion Approximately 3 Feet Per Second.

crease the speed of cooling at the center and decrease it at the surface of the body.

2. Surface Condition of the Metal

a. Oxidation

Most of the experiments relating to surface cooling were repeated one or more times on the same samples without attempting to remove the adhering oxide from the previous heating and cooling. Frequently, though not invariably, the first cooling was somewhat slower than the second, third, or succeeding coolings. However, in some cases the most rapid cooling was observed the first time.

Such variations might originate from one or both of the following causes; (1) Change in thermal properties of the steel resulting from structural changes brought about by the previous heating and cooling, (2) Variations in the condition of the surface of the metal samples, especially with respect to scale thickness and adherence of the oxide to the underlying metal.

The comparisons of copper and steel spheres, just cited, indicate that the surface cooling should not be affected appreciably by any changes which can normally be expected in the thermal properties of steels at high temperatures. Practical experience indicates

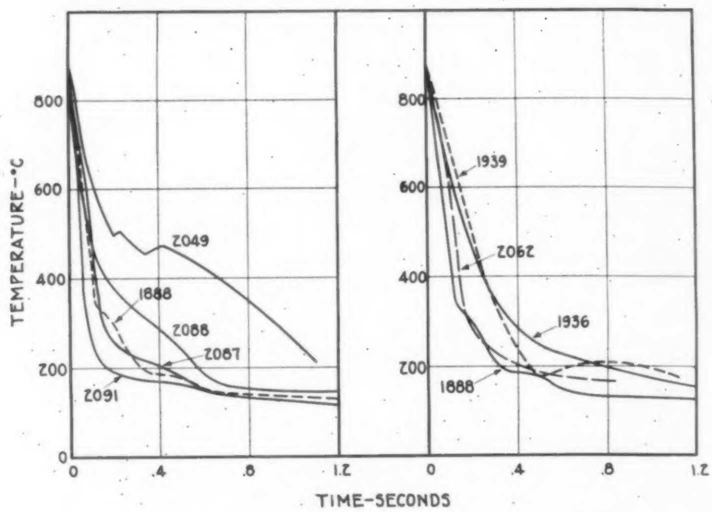

Fig. 56—Effect of Manner of Heating on the Surface Cooling Curves for a 1-Inch Sphere Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at About 3 Feet Per Second. Test 1888—Steel Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 1936—Steel Heated in Illuminating Gas, Held 10 Min. at 875 Degrees Cent. (1605 Degrees Fahr.). Test 1939—Steel Heated in Nitrogen, held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2049—Nickel Plated Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 206—Steel Heated in Muffle Containing Sawdust, held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2087—Blued Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2088—Steel Heated in Air, Held 1 Hour at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2091—Steel Heated in Salt Bath, for 10 Min. at 875 Degrees Cent.

that surface cooling can be affected appreciably by the condition of the metal surfaces.

Cooling curves were taken on heavily oxidized samples and on samples so heated as to minimize the oxidation of the surfaces of the spheres. Tests were also made on nickel plated spheres and the results are summarized in Table XIV and Figs. 56, 57, and 58.

Several methods were used to minimize oxidation in heating. Samples were heated in a muffle containing sawdust, in a salt bath and in atmospheres of nitrogen or illuminating gas. Heavily oxidized samples were prepared by bluing in potassium nitrate mixed with manganese dioxide and by long heating at the high temperatures before quenching.

Although oxidation during heating was minimized by the illuminating gas and nitrogen atmospheres, it should not be assumed that the samples were clean and free from all oxide. Oxidation can take place during cooling in water where the highly heated steel is mo-

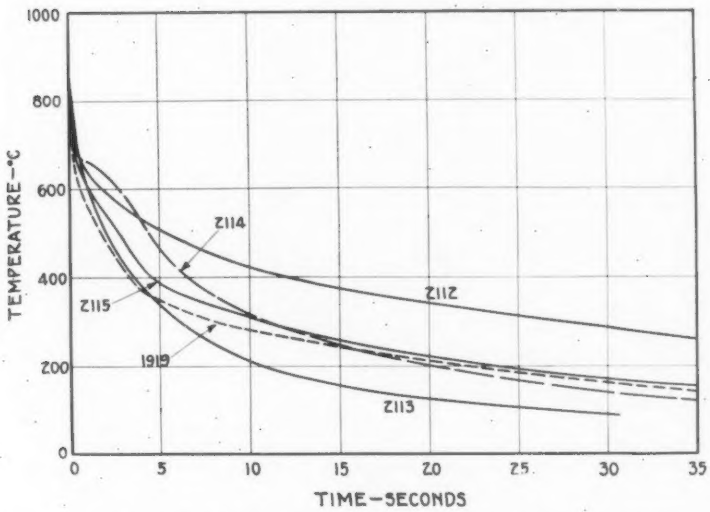

Fig. 57—Effect of Manner of Heating on the Surface Cooling Curves for a 1-Inch Sphere Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into No. 2 Oil at 20 Degrees Cent. (65 Degrees Fahr.), Moving at About 3 Feet Per Second. Test 1919—Steel Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2112—Steel Heated in Air, Held 1 Hour at 875 Degrees Cent. (1605 Degrees Fahr.). (Note Adhering Scale.) Test 2113—Steel Heated in Air, Held 1 Hour at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2114—Nickel Plated Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2115—Steel Heated in Nitrogen, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.).

mentarily in contact with steam, gases originally in solution, or those resulting from the decomposition of the coolant. Furthermore, the heated steels (except samples heated in salt) were momentarily in contact with air during transfer from the furnace to the coolant.

Fig. 56 shows that the surface cooling in water of the heavily oxidized samples did not differ appreciably from that of the samples heated for the normal short period in air. On the other hand, the surface cooling of the nickel plated spheres was somewhat slower than that of the corresponding unplated samples, but the differences were small. The nickel was deposited on the spheres subsequent to welding the thermocouples to the surface of the steel and this may have had the effect of placing the thermal junction enough below the surface in contact with the coolant to increase the recorded cooling times. However, it should be noted that the nickel oxide produced in heating the samples remained more nearly intact and was not so easily detached from the underlying metal when immersed in water as was the iron oxide scale on the unplated spheres. If the predominating cause of reduced speeds of cooling is the insulating effect of a complete envelope of oxide, considered to have low

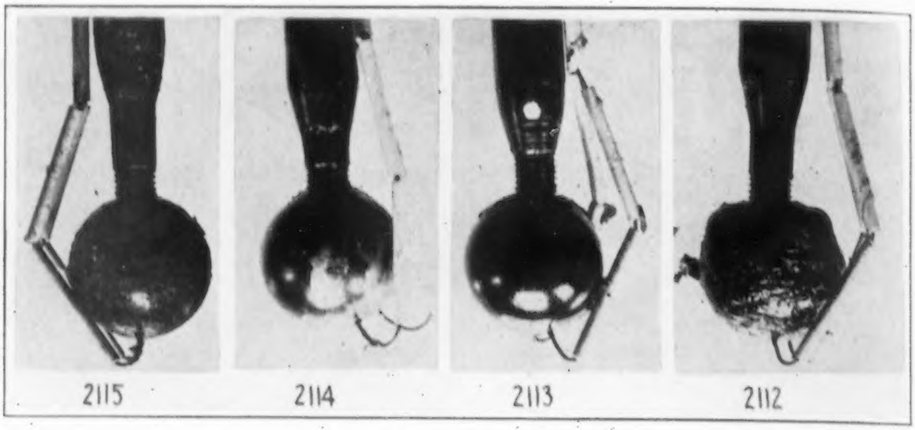

Fig. 58—Photographs of the Oil-Quenched Spheres Referred to in Fig. 57. × ⅔.

thermal conductivity or due to a loosely adherent scale which tends to trap gases, then heavily oxidized samples should show slower cooling, at both surface and center, than slightly oxidized samples, if quenched in coolants which do not tend to break up the continuity of the iron oxide film.

Center cooling curves for spheres quenched in oil, which are reproduced in Fig. 57, show this to be the case and when compared with photographs of the quenched specimens, in Fig. 58, furnish a striking illustration of possible effects of adherent oxide. For example, samples 2112 and 2113, Fig. 58, were heated and quenched in the same manner. In 2112 the scale was left as an envelope around the sample, whereas in the duplicate specimen, 2113, most of the scale was broken off. The cooling curves in Fig. 57 show that the sample with the scale envelope cooled very much more slowly (test 2112) than the duplicate (test 2113) in which the scale was broken off in the coolant.

The differences illustrated in Fig. 57 are not all so large as in the case mentioned, but there are wide variations in the cooling curves which clearly indicate that the manner of cooling may be appreciably affected by the character of the oxides at the surfaces of the pieces.

In practical heat treatment such conditions are reflected by lack of uniformity of results and, depending upon the size and shape of the parts and composition of the steel under treatment, may make it difficult to secure the desired hardness. Such effects would be most important in sizes in which only surface hardening can be obtained with the selected steels and coolants. However, lack of uni-

form hardening in steels generally introduces the problem of internal stresses and when the stresses, hardness and cooling curves can be correlated a better conception will be obtained of the importance of the described differences in the cooling curves.

A carbon deposit was obtained on most of the samples heated in illuminating gas which decreased the speeds of surface cooling on water quenching. There was little difference in the cooling curves obtained on samples heated for short periods in air and those heated in the presence of sawdust or in an atmosphere of nitrogen. However, there was a tendency toward retarded cooling on samples heated in nitrogen.

These samples did not have a heavy scale but showed evidence of oxidation of a type which adhered tenaciously to the underlying steel. This substantiates the view that oxide retards the cooling only when it adheres to the metal. Slight oxidation accompanied by good adherence, or heavy adherent scale such as might be expected on some alloy steels, tends to retard cooling even in water quenching. Scale, which is readily blown off by gas evolution in aqueous solutions, does not seem to affect the cooling appreciably. All oxide coatings become of more importance in less drastic media in which the conditions tend to preserve the continuity of the coating.

The fact that scale is actually blown off the surface of the steel when quenching in water and aqueous solutions can readily be shown if the quenching is carried out in a glass container. Figs. 59 and 60 containing enlarged photographs from motion picture films taken through a glass tank illustrate the features mentioned. It will be noted that the action is very much more violent in 5 per cent sodium hydroxide than in ordinary tap water and is accompanied by a wider distribution of gas and turbulence. The photographs show one of the features which probably contribute to the uniformity obtained in practice with sodium hydroxide solutions since their relatively violent action in contact with hot steel tends to compensate for deficiencies in circulation.

One of the interesting features shown in Table XIV and Fig. 56 is the comparison of the water cooling of samples heated in air and those heated in the salt bath. The latter cooled in appreciably shorter time than the former and the quenched sphere was relatively clean and looked like steel which had been heated in air and quenched in 5 per cent sodium hydroxide. The increased speed of cooling of the samples heated in the salt bath may be ascribed to the elimina-

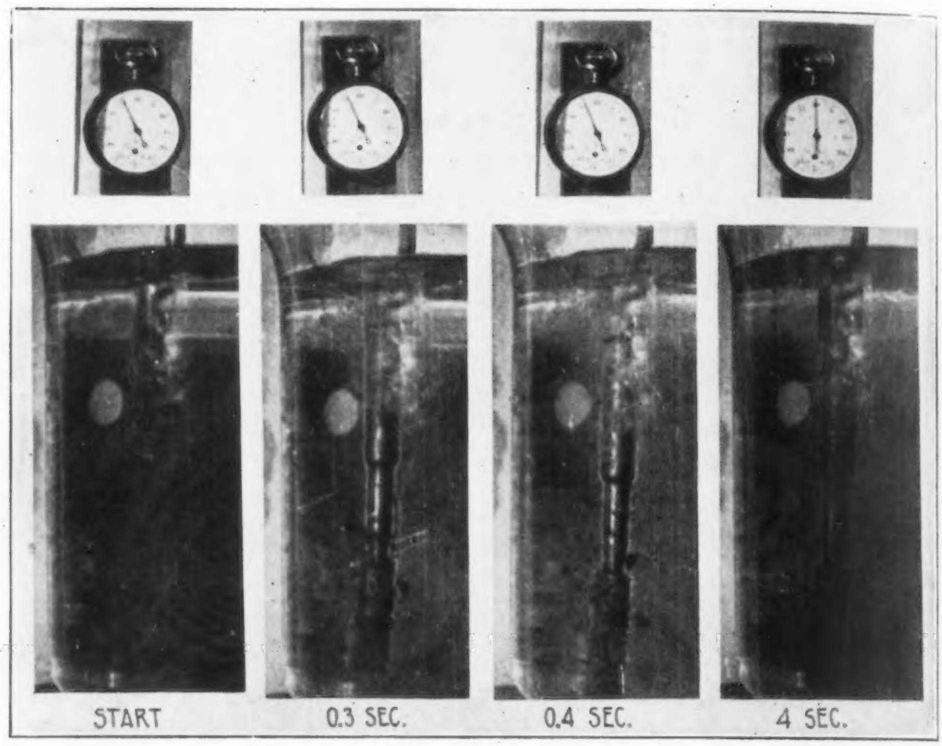

Fig. 59—Photographs Taken During Quenching of a ½-Inch Diameter by 2-Inch Steel Cylinder Quenched in Motionless Water at About 20 Degrees Cent. (65 Degrees Fahr.). The Cylinder Was Quenched at 875 Degrees Cent. (1605 Degrees Fahr.). Compare the Evolution of Gas and Distance Traveled by the Scale Blown Off the Specimen with Similar Effects in Sodium Hydroxide.

tion of scale in the heating and to the solution of the adhering salt by the water adjacent to the hot metal upon introduction into the coolant. The importance of the latter effect is indicated by the fact that the cooling at the surface of the sample heated in salt and quenched in water was about the same as that of steel heated in air and quenched in 10 per cent sodium or calcium brines.

Apart from possible insulating effects, oxide may affect the cooling in two other ways. Oxidation frequently pits the surface and the irregularities may tend to promote adherence of gas. Oxide, even when smooth, may differ from steel in its ability to hold gas bubbles formed or released in the coolant during quenching.

Some of the seemingly obvious methods of minimizing oxidation are not always effective in that they may leave a thin, adherent oxide coating on the steel. This is sometimes the result of sealing the furnace doors to exclude free inflow of air. If instead, the furnace is vented, greater oxidation will take place but the scale will

often become detached more readily when the heated metal is immersed in the coolant and more uniform and effective hardening be obtained.

Such methods can be satisfactory for metal which is to be tempered and machined after treatment but cannot be used effectively for some dies or other parts which are used in a hard condition and must be treated after machining. The practices employed in such cases vary widely to meet individual requirements and include heating in carbonaceous materials, the use of molten metal or molten salt baths, regulation of furnace atmospheres, etc. Steel or iron plates have been placed over the working portions of dies, sometimes with interposed newspaper, which chars and does not burn under such conditions, all with the object of maintaining an effectively clean metal surface preparatory to quenching. The effectiveness of the different methods will depend upon the application and the care with which the work is done, and frequently this matter controls the success of the treatment. It therefore frequently warrants the most detailed attention.

b. Smoothness

Brophy[25] has already shown that the degree of roughness of surface may have an appreciable effect upon the results obtained in quenching through variations in the adherence of gas formed in the coolant. Ground samples showed fewer soft spots than samples with surfaces roughened by knurling. This was ascribed to the stronger tendency for gas bubbles to cling to the roughened surface.

Comparisons are given in Figs. 62 and 63 of the center and surface cooling in smooth ground and "knurled" spheres when quenched in water and likewise in oil. The spheres were knurled as illustrated in Fig. 61.

In both oil and water quenching the cooling was slower in the roughened spheres than in those which were ground. The differences were greater in oil than in water quenching and in the latter case were larger for the surface than for the center.

The effects observed in water quenching were probably the result of steam being more readily trapped by the knurled surface; in the case of the oil-quenched samples it seemed probable that the rela-

[25]General discussion of paper by S. Epstein and H. S. Rawdon: "Progress in Study of Normal and Abnormal Steel," TRANSACTIONS, American Society for Steel Treating, Vol. 12, 1927, p. 413.

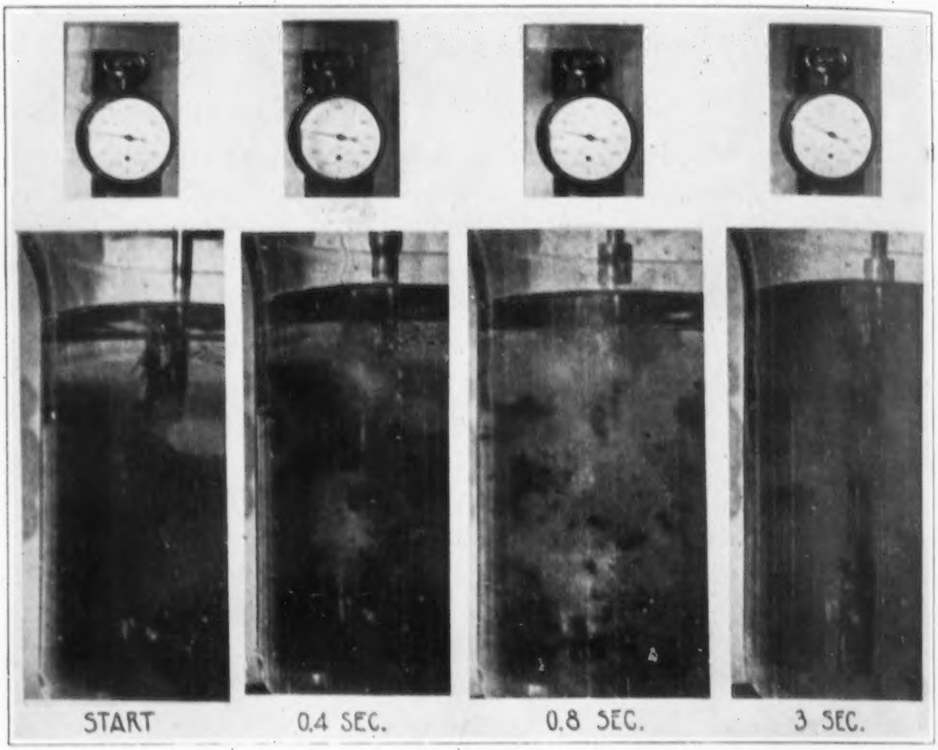

Fig. 60—Photographs Taken During Quenching of a ½-Inch Diameter by 2-Inch Steel Cylinder Quenched in 5 Per Cent Sodium Hydroxide. The Cylinder was Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) into the Motionless Coolant at About 20 Degrees Cent. (65 Degrees Fahr.). Note Particularly the Violent Action and the Distance Traveled by the Scale Blown Off the Specimen.

tively large differences were due to the combined effects of any trapped gas and adherent scale since the knurled spheres had a nearly complete oxide envelope subsequent to quenching. However, in both water and oil the decreases in speeds of cooling resulting from the roughened surface were of sufficient magnitude so that they could contribute to an important degree to lack of uniform hardening in practice.

c. *Relation of surface to the oil used*

Discussion of the effects of oxidation and smoothness upon the cooling of steel spheres will not dispose of the matter of the influence of the surface conditions upon the cooling of metals. In the course of experiments in which small cylinders were quenched in various oils evidence was obtained that effects produced by variations in the condition of the metal surface might be different in different coolants. In other words, the relation between the metal surface and the cool-

Fig. 61 — Photograph of the Knurled Sphere Used. × 1.

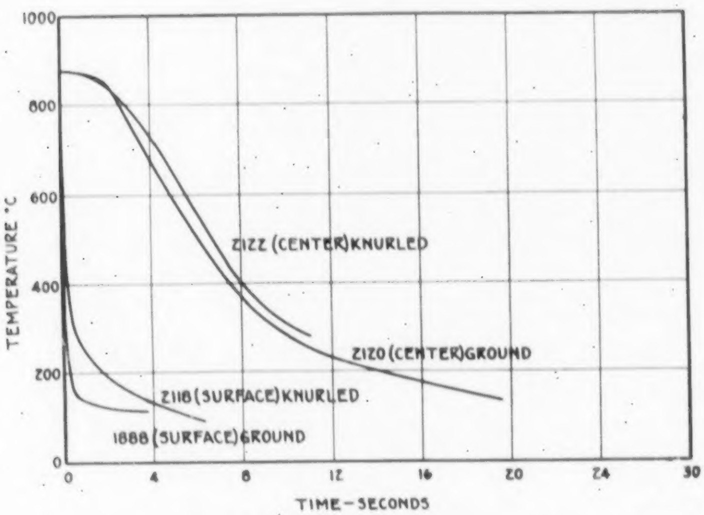

Fig. 62—Center and Surface Cooling Curves of Smooth Ground and Knurled 1-Inch Spheres Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion About 3 Feet Per Second.

ant, as well as variations in the metal surface, may play a part in determining the manner of cooling.

The cooling curves upon which the following discussion is based were obtained at the center of cylinders ½-inch in diameter and 2 inches long. The tests were made as the result of a statement by Rodman and Boren[26] that "certain oils of low viscosity and low flash point may have their initial quenching speed materially increased by adding thereto a comparatively small proportion of oil of high flash point and high viscosity." As an example, it was stated that there may be added to 100 parts of an ordinary Pennsylvania neutral oil

[26]U. S. Patent 1,535,379, April 28, 1925.

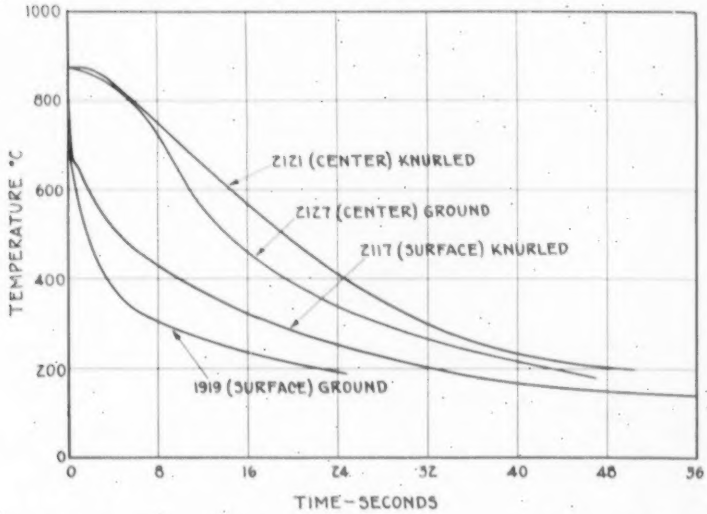

Fig. 63—Center and Surface Cooling Curves of Smooth Ground and Knurled 1-Inch Spheres Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into No. 2 Oil at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion About 3 Feet Per Second.

having a viscosity of about 70 seconds at 26.6 degrees Cent. (100 degrees Fahr.), and a flash point of about 177 degrees Cent. (350 degrees Fahr.), about 10 parts of a heavy residuum oil derived from Pennsylvania crudes ("steam refined oil"), having a flash point of about 327 degrees Cent. (620 degrees Fahr.) and a viscosity of about 200 seconds at 100 degrees Cent. (212 degrees Fahr.). It was claimed that such a mixture "will quench red hot steel from about 815 degrees Cent. (1500 degrees Fahr.) down to about 650 degrees Cent. (1200 degrees Fahr.) in less than half the time required by any commercial quenching oil" which could be found on the market.

The idea of adding an oil of high viscosity to one of low viscosity to increase speed of cooling is probably contrary to popular conceptions, although it is generally recognized that the speed of cooling is not solely dependent upon viscosity. As is shown in Fig. 64 the speed of cooling in Pennsylvania pale neutral oil of about 100 seconds viscosity (hereafter referred to as "pale neutral" oil) was materially increased at temperatures around 600 to 800 degrees Cent. (1110 to 1470 degrees Fahr.) by the addition of 5 per cent of a Pennsylvania residuum oil of about 3500 seconds viscosity (hereafter referred to as "residuum" oil). Similar increases were observed with additions of 10 and 15 per cent of the residuum oil to the pale neutral oil but the magnitude of the effects was somewhat less than was claimed by Rodman and Boren for their samples.

Table XV
Comparisons of Center Cooling when Quenching ½-inch Diameter by 2-inch Cylinders in Different Oils[1]

Item	Oil	Seconds to cool from 800 to 600 degrees Cent. (1470 to 1110 degrees Fahr.)
1	Pale neutral oil	6.3
2	Pale neutral plus 5 per cent residuum	4.3
3	Prepared (commercial) oil No. 2	6.1
4	Prepared (commercial) oil No. 1	5.1

[1]Samples prepared from 0.95 per cent C steel.

Table XV shows the magnitude of these changes in relation to customary commercial quenching oils. Item (1) is the pale neutral oil, (2) the pale neutral oil plus 5 per cent by volume of the residuum oil, (3) a fairly "rapid" commercial quenching oil and (4) the most "rapid" commercial quenching oil tested up to the time the described experiments were made.

Similar results were obtained in quenching chromium plated steel cylinders but the numerical values of the cooling rates (Fig. 64) were all lower than in the uncoated samples. While somewhat irregular results were obtained in corresponding experiments with nickel plated cylinders, there was no appreciable increase in speed of cooling produced by the addition of small proportions of residuum oil to the pale neutral oil.

The results of these experiments raise two questions:—(1) what are the causes of the increased speeds of cooling for the steel cylinders produced by adding small quantities of the heavy oil to the light, and (2) why was the same increase in cooling rate not observed in samples coated with various metals such as nickel and chromium.

While some further work was done in attempting to find an explanation, none can be advanced with supporting evidence at this time. In any case, it would seem that the answer to both questions will involve the relation between the metallic surface and the coolant.

3. Effect of Gases Dissolved or Formed in the Coolant

It is known that the gas adhering to the surface of a metal during quenching may appreciably change the manner of cooling in a given coolant. The result may be a general decrease in the hardness of the quenched steel or the effects may be localized so that the steel is not uniformly hard.[27] The soft spots in such cases may be

[27]S. Epstein and H. S. Rawdon: "Progress in Study of Normal and Abnormal Steel," Transactions, American Society for Steel Treating, Vol. 12, 1927, p. 337.

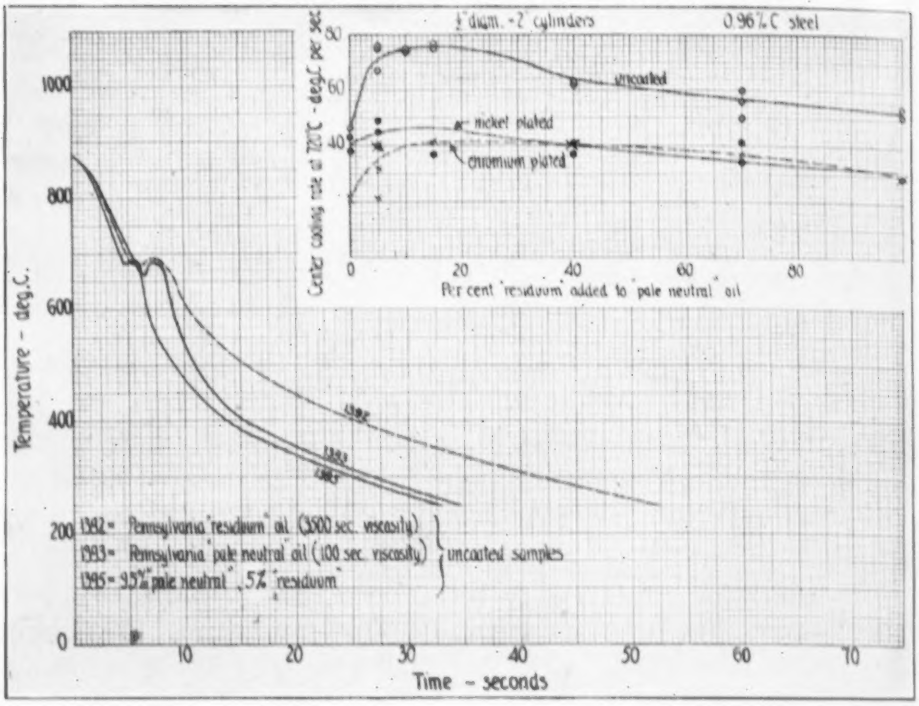

Fig. 64—Effect of Additions of Pennsylvania Residuum Oil to Pale Neutral Mineral Oil on the Center Cooling of Steel Cylinders. See Text for Details of These Experiments.

discolored and seem to indicate a reaction between the metal and the gas with which it was in contact.

Fig. 65, representing surface cooling curves of 1-inch spheres quenched into water containing different amounts and kinds of gases, shows that the magnitude of the effects of dissolved gases may vary widely. In all cases illustrated, the gas was passed through the water for a considerable period to produce saturation at atmospheric temperatures and pressures before quenching.

The cooling curves obtained were practically the same for boiled water, Washington city (tap) water and water saturated with oxygen. Retarded cooling was observed, particularly at temperatures in the neighborhood 400 to 150 degrees Cent. (750 to 300 degrees Fahr.) in water saturated with air but the greatest effects were obtained with water saturated with carbon dioxide. This gas is soluble in relatively large proportions in water and the cooling was very much slower than that in tap water in the range 600 to 150 degrees Cent. (1110 to 300 degrees Fahr.).

The fact that carbon dioxide was the most effective of the gases

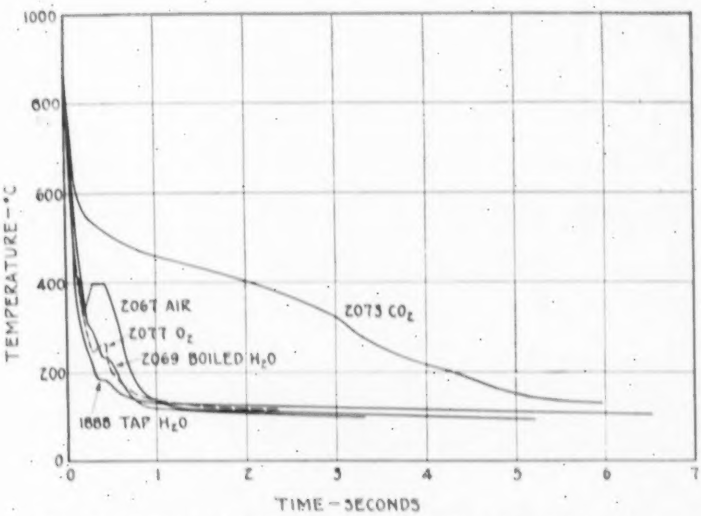

Fig. 65—Effects of Different Dissolved Gases Upon the Surface Cooling in Water Quenching. 1-Inch Steel Spheres Quenched from 875 Degrees Cent. (1605 Degrees Fahr.); the Water was 20 Degrees Cent. (65 Degrees Fahr.) and Moving at About 3 Feet Per Second.

studied in retarding the cooling may be ascribed in large part to its high solubility in water.

Visible evidence of the possible importance of dissolved gases in water is given in Fig. 66 in which are reproduced photographs from a motion picture taken during the quenching of a 1-inch sphere in water saturated with carbon dioxide. The large evolution of gas continues throughout the major portion of the time of immersion. In contrast with the effects observed in sodium hydroxide solutions (Fig. 60) the action is not violent and it is reasonable to suspect that many gas bubbles have adhered to the surface of the sphere to produce the effects shown in Figs. 65 and 66.

The decrease in speeds of cooling is not the only feature to be considered. An important characteristic is the instability at the metal-coolant contact surfaces. This is shown both by the character of the cooling curves and by the increased difficulties which were encountered in reproducing results. With respect to the latter, it should be kept in mind that the curves shown in Fig. 65 give an approximation to what happens over only a small spot on the surface. However, the difficulty of reproducing such cooling curves is a reflection of conditions which probably obtain over the entire surface. Lack of uniformity is one of the principal difficulties which can be expected in practical heat treatment when quenching in water containing much dissolved gas.

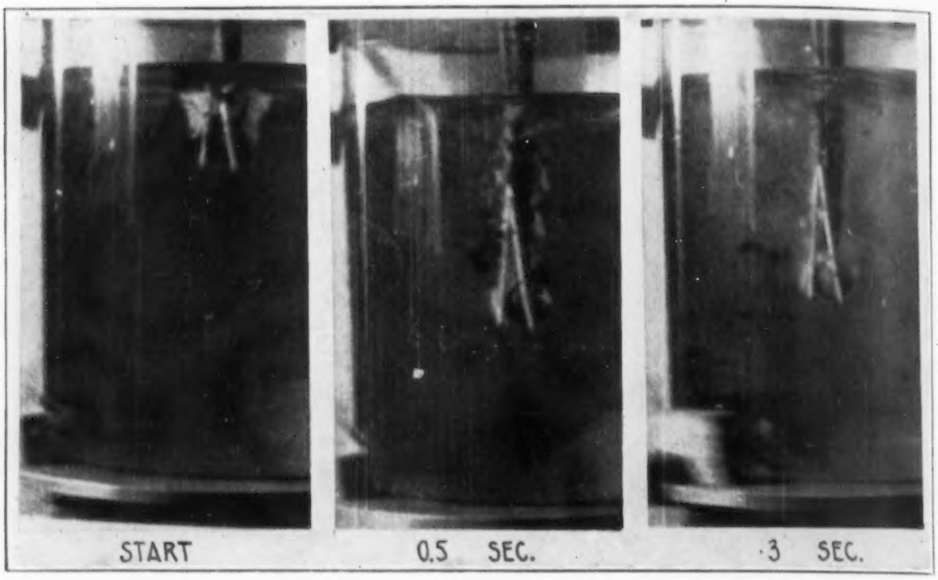

Fig. 66—Photographs Taken During Quenching of a 1-Inch Steel Sphere in Water Saturated with Carbon Dioxide. The Sphere was Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at About 20 Degrees Cent. (65 Degrees Fahr.). Motion of the Coolant, Produced by Rotation of the Glass Tank, was About 3 Feet Per Second. Note Release of Gas and Pieces of Scale Blown Off the Specimen.

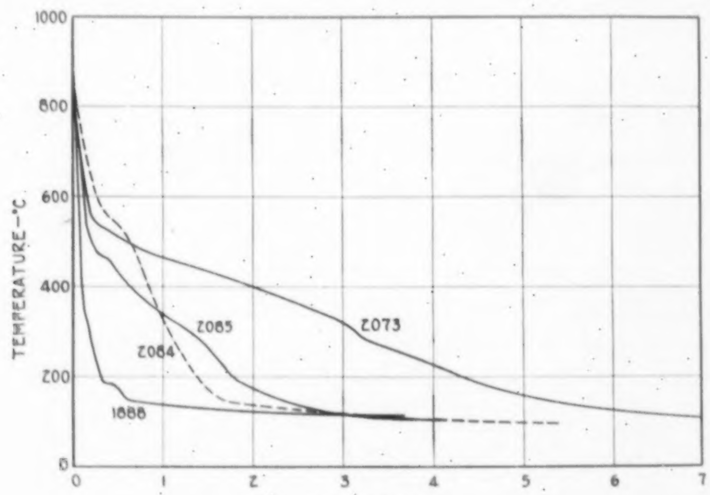

Fig. 67—Effect of Manner of Heating on the Surface Cooling Curves of 1-Inch Spheres Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water Saturated with Carbon Dioxide. Water Temperature 20 Degrees Cent. (65 Degrees Fahr.), Coolant Motion About 3 Feet Per Second. Test 2073—Steel Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2084—Nickel Plated Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 2085—Blued Steel, Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.). Test 1888 for Comparison, Represents Steel Heated in Air, Held 10 Minutes at 875 Degrees Cent. (1605 Degrees Fahr.) and Quenched Into Tap Water.

The character of the metal surface may also play a part in the effects produced by given quantities and types of gases. As is shown in Fig. 67, representing samples quenched in water saturated with carbon dioxide, the greatest retardation in cooling was obtained in the samples heated in the ordinary manner in air. Less retardation, but equal instability, was observed in the nickel plated spheres heated in air and in the spheres blued prior to heating in air for quenching.

It is probable that in practical heat treatment the three variables, oxidation, roughness of surface and adhering gas formed by or released from the coolant, go hand in hand and that the difficulty in procuring the desired hardness is often the result of the combined effects of these three. When neglected they may contribute largely to erratic and non-uniform results but under suitably controlled conditions the magnitude of their effects may be considerably decreased.

Chapter IV

COOLANT CIRCULATION

1. Rates and Direction of Motion

A factor of great practical importance is the circulation of the coolant or its converse, the motion of the sample with respect to the coolant. In considering this subject, attention should be given not only to the circulation subsequent to immersion but also to the flow around the steel as it is being lowered within the coolant. This latter has special significance in the case of small pieces immersed in rapid coolants such as water where the surface of the sample may reach a temperature of 150 degrees Cent. (300 degrees Fahr.) or even less in the time that the sample is being lowered within the bath.

Tests reported by Haler[28] indicate that there is a wide variation in speed of action of different individuals in hand quenching; in his tests the average velocity of specimens varied from about 3.5 to 6 feet per second for a 20-inch travel. There was also deceleration from start to finish, whereas in gravity quenching the velocity varied from close to 0 at the moment of release of the piece from the tongs to values in the neighborhood of 3 feet per second.

In most of the experiments with small specimens already described, the gravity quenching method was employed for lowering

[28] P. J. Haler: "Quenching: A Practical Study on Rapid Cooling," *Mechanical Engineering*, Vol. 49, 1927, p. 1187.

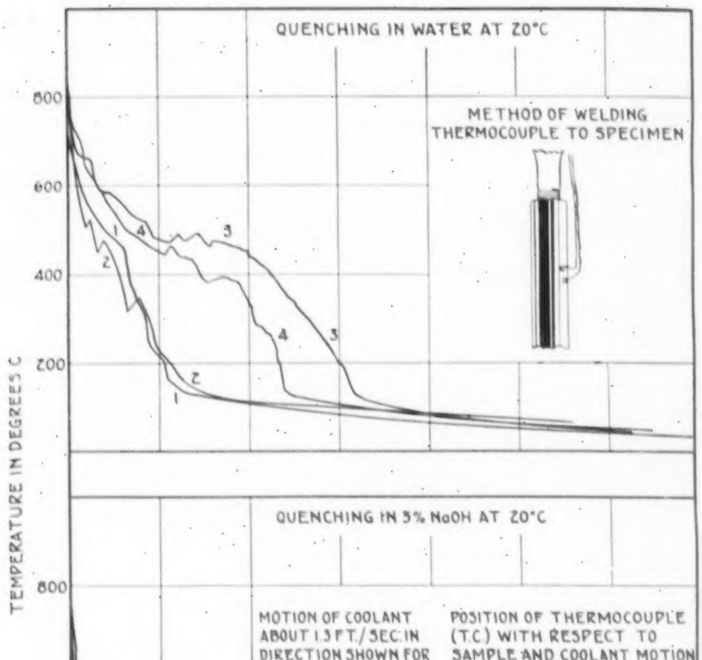

Fig. 68—Cooling at Different Parts of the Surface When Quenching Small Cylinders in a Rotating Bath of Water or 5 Per Cent Sodium Hydroxide. Cylinders ½-Inch Diameter by 2 Inches Long of 0.95 Per Cent Carbon Steel. Temperatures Determined with 32 B and S Gage Thermocouple.

the samples into the bath at a location where the coolant was moving at approximately 3 feet per second. This method probably helped materially in reproducing the quenching conditions but the samples are known not to have cooled uniformly at different parts of their surfaces. It is interesting to note the differences in cooling encountered in water quenching cylinders ½-inch in diameter, and to compare them with cooling in 5 per cent sodium hydroxide under corresponding conditions.

For convenience, the area which meets the direct flow of the

Table XVI
Hardness of the Surface of 0.95 Per Cent C Steel Cylinders at Different Points Around the Circumference when Cooled as Shown in Fig. 68[1]

Specimen and Test Number	Average Rockwell Hardness (C Scale) Front	Sides	Back
12048	64.7	59.5	57.5
		63.4	
12047	57.4	54.6	54.4
		49.8	
12046	58.6	46.3	46.0
		48.5	
13001	64.2	63.7	63.0
		63.9	
Average	61.2[2]	56.2[3]	55.2[2]

[1]Cylinders ½-inch diameter by 2 inches long.
[2]From about 32 hardness tests.
[3]From about 64 hardness tests.

coolant (position 1, Fig. 68) will be called the front; the area opposite this (position 3) the back, and the areas between these two, (positions 2), the sides.

In water quenching the back cooled much more slowly than the front and sides. This is, perhaps, to be expected from the manner in which the liquid is conceived to flow around the cylinders under the circular motion of the coolant used in the experiments. The sides represent transition areas from the zone of most rapid cooling to the zone of slowest cooling and the manner of cooling of the sides may be expected to vary depending upon the exact conditions encountered. In the case recorded in Fig. 68, the sides and front cooled in much the same manner but in duplicating the experiments slow cooling of the sides was sometimes observed.

The magnitude of the differences between front and back positions is shown by the fact that the front dropped to 200 degrees Cent. (390 degrees Fahr.) in about 2 seconds in water while the back required about 6 seconds to reach the same temperature. This was longer than was required when quenching in motionless water.

When translated into terms of practical heat treatment these variations in the surface cooling curves may mean variations in the hardness of the quenched product. Differences in the hardness around the circumference were observed even in the small cylinders of 0.95 per cent carbon steel used in the experiments. As is shown in Table XVI, the back was generally somewhat lower in hardness and showed more "soft spots" than the front. The sides varied, some-

times they approached the hardness of the front and at other times the hardness of the back. In some cases uniform hardness was obtained all over the surface but as indicated by many of the hardness tests and the cooling curves the described manner of circulating the coolant was not adequate to produce a uniform product regularly, when quenching in water.

A different situation was found when quenching in 5 per cent sodium hydroxide. As is shown in Fig. 68, the cooling was quite uniform from point to point around the circumference. Under the conditions of the experiments, coolant circulation was much less important in the sodium hydroxide than in the water.

It is evident from these results that sodium hydroxide is better able than water to make up for deficiencies in circulation but that circulation adequate to produce the desired hardening at the point of slowest cooling is essential in securing uniform results. More rapid flow of the coolant at one point may not be sufficient; the flow must be regulated over the entire surface.

Fig. 68 illustrates the ease with which the cooling may be retarded by "pockets" of slowly moving or "stagnant" liquid and the reason why the so-called "figure 8" or "S" quench is advantageous. Linear motion of the specimen, or of the coolant, will tend to leave "pockets" of slow flow and often result in "soft spots," whereas if the path of the specimen follows a figure 8 each point on the surface will be "wiped" by the coolant at least during a part of the cooling time and the chances of securing uniform hardening all over will be enhanced appreciably.

There are, of course, several ways of preventing these "soft spots" which are due directly to deficiencies in circulation. One obvious method is to provide adequate circulation, another is to select coolants which, without appreciable motion, will provide cooling rates in excess of the requirements. Both aim to provide faster cooling so that there will be a safety factor.

While it is generally considered to be good practice to select coolants which will give cooling rates well above those required to harden the steel, there can be no substitute for circulation which provides *uniformity* from point to point on the surface of steels during quenching. The reason for this will become apparent when it is recalled that the hardening transformations are accompanied by volume changes which leave the quenched steels in a state of stress. If the cooling is not uniform the time at which the volume changes will oc-

cur will vary from one area to another and this can readily increase the magnitude of the stresses set up in the metal. In fact it is probable that much of the trouble with the cracking of steels in quenching is due to lack of uniformly rapid cooling rather than to rapid cooling alone. Further reference will be made to this matter in the discussion of hot aqueous solutions.

Many methods have been employed to meet the varied industrial requirements of uniformly rapid cooling and a record of even a small number of these would be instructive and useful. However, a more important aspect of this matter is an appreciation of the principles involved, for then the details can be worked out for individual applications. Uniform cooling requires a uniform flow of the liquid past all positions on the surface of the metal bodies. In the ordinary liquids employed in quenching the rate of flow must be sufficiently high to remove the gases released from or formed by the coolant at the heated metal surfaces and preferably also to minimize the formation or release of gases by making more of the liquid pass a given point per unit of time. Fig. 68 shows that linear flow of the liquid does not approach the ideal conditions closely, although this method may be satisfactory in quite a few cases. Quenching baths which are provided only with inlet and outlet pipes are not so correctly designed as those systems which impart a complex swirling motion to the coolant.

If baths are provided only with inlet and outlet pipes and no special circulating system it is desirable to impart as vigorous and irregular motion to the sample as the conditions will allow, especially if water is the coolant.

2. Spray Quenching

One of the effective methods of obtaining uniformly rapid cooling is by the use of water sprays. Very large increases in strength can be obtained in low carbon steels, which do not harden appreciably in ordinary water bath quenching, by heating the steel to high temperatures and quenching in a high pressure water spray. Smith[29] made practical application of this method of quenching, and has been able regularly to produce bolts showing tensile strengths of over 100,000 pounds per square inch with high values of reduction of

[29]R. H. Smith: "High Tensile Strengths with Low Carbon Steels," *Proceedings*, American Society for Testing Materials, Vol. 24, part II, p. 618 (1924). See also "Some Physical Properties of Low Carbon Steel," Transactions, American Society for Steel Treating, Vol. 7, No. 5, p. 569 (1925).

Table XVII

Mechanical Properties of 0.07 Per Cent C Steel Quenched in Various Ways from 940 Degrees Cent. (1725 Degrees Fahr.)
(C, 0.07 Mn, 0.27 P, 0.006 S, 0.054 Si, 0.001 Cr, 0.07) (a)

Spec. No.	How quenched	Water Line Pressure lbs. per sq. inch	Prop. Limit	Yield Point	Tensile Strength	Breaking Strength (c)	El. in 2 inches, Per Cent	Red. Area, Per Cent	Area under stress-strain curve, square inch	Izod impact, energy absorbed foot pounds (b)
			Lbs. per square inch							
C6- 1	"As rec'd"		15,000	37,300	47,300	113,000	48.0	74.6	2.20	71, 72, 71 Average 71.3
C6- 2	H_2O bath at 18° C.	none	25,000	45,600	67,400	139,500	24.0	71.1	1.48	83, 84, 76 Average 81.0
C6- 3	H_2O spray,	20	contin. curve	81,200	103,600	164,000	13.5	50.3	1.32	
C6- 4	18° C.	20	32,000	84,500	110,000	160,000	14.0	49.0	1.37	
C6- 5	H_2O spray,	40	38,000	73,900	91,500	166,500	15.5	59.7	1.19	57, 63, 66
C6- 6	18° C.	40	39,000	79,000	102,000	167,000	12.5	52.6	1.20	Average 62.0
C6- 7	H_2O spray,	60	42,000	86,300	112,100	150,000	9.0	36.5	0.89	
C6- 8	18° C.	60	38,500	70,500	96,600	145,000	15.0	46.3	1.31	
C6- 9	H_2O spray,	85	contin. curve	74,200	95,600	170,000	18.0	57.4	1.54	43, 48, 60
C6-10	18° C.	85	28,500	85,000	104,800	148,500	10.0	39.2	0.96	Average 50.3

(a) Tensile specimens had a reduced section approximately 0.435 and 2¼ inches long.
(b) Izod specimens had a V-notch and were of standard dimensions.
Specimens (a) were held 15 minutes and (b) 10 minutes at 1725 degrees Fahr. before quenching.
A "double-slope" or nearly continuous curve was shown in most stress-strain diagrams, making difficult the determination of prop. limit. In the double-slope curves the upper limit was taken.
(c) The load at the moment of fracture divided by the area of the fractured section.

Table XVIII

Mechanical Properties of 0.25 Per Cent C Steel (Boiler Plate) Quenched in Various Ways from 885 Degrees Cent. (1625 Degrees Fahr.)

Spec. No.	How quenched	Water Line Pressure lbs. per sq. inch	Prop. Limit	Yield Point	Tensile Strength	Breaking Strength	El. in 2 inches, Per Cent	Red. Area, Per Cent	Area under stress-strain curve, square inch	Izod impact, energy absorbed foot pounds
			Lbs. per square inch							
C31-1	"As rec'd"		21,000	32,000	61,750	121,500	37.5	60.6	1.35	12, 20.5, 16 Average 16.2
C31-2	H_2O bath at 18° C.	none	25,000	.....	166,300	181,800	2.5	9.3	.71	11, 15, 31 Average 19
C31-3	H_2O spray, 17° C.	20	.....	.....	193,900	208,600	3.5	7.1	.72	11.5, 10, 16 Average 12.5
C31-4	H_2O spray, 17° C.	40	36,000	.....	192,600	241,000	6.5	17.3	1.04	
C31-5	H_2O spray, 17° C.	60	41,000[1]	.....	200,500	219,300	6.5	10.7	.70	
C31-6	H_2O spray, 17° C.	85	42,000	.....	191,400	206,000	2.5	7.8	.60	10, 18, 16 Average 14.7

[1]Double slope—upper one used.

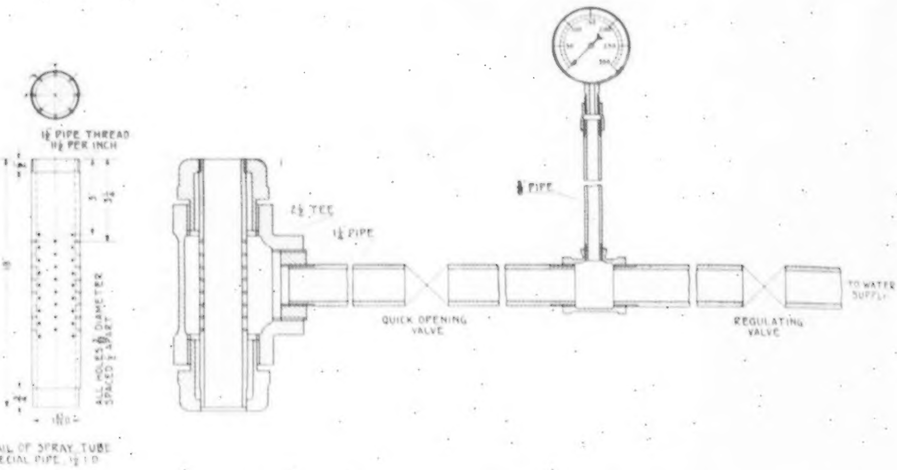

Fig. 69—Sketch of the Equipment Used in High Pressure Water Spray Quenching.

area in carbon steels containing only 0.09 to 0.15 per cent carbon.

As an illustration of the effects of pressure spray quenching on low carbon iron alloys there are grouped in Tables XVII to XX, the results of laboratory tests of 0.25 per cent carbon and 0.07 per cent carbon steels, American ingot iron and wrought iron. Izod impact test results are given in addition to the tensile properties and in some cases comparisons are given between the results of pressure spray quenching in water and quenching in a bath containing 5 per cent sodium hydroxide.

A sketch of the spray used in these experiments is shown in Fig. 69. Specimens for the tensile and Izod impact tests were introduced into the quenching chamber after the spray had been turned on under the designated line pressures. Specimens used for the cooling curves were first introduced into the chamber and then suddenly subjected to the full line pressure by means of the quick opening valve (Fig. 69); the line pressure then quickly dropped to the values recorded in the individual cases. This latter procedure resulted in a variable but short interval of slow cooling at temperatures just below those at which the steels were quenched. (Figs. 70 and 71). This did not affect the comparisons in view and eliminated certain difficulties experienced when introducing specimens into the spray already under line pressures.

As is shown in Table XVIII, the pressure spray quenching of the steel containing 0.25 per cent carbon regularly produced tensile strengths of over 190,000 pounds per square inch but the steel was

Table XIX
Mechanical Properties of American Ingot (Armco) Iron Quenched in Various Ways from 960 Degrees Cent. (1760 Degrees Fahr.)

Spec. No.	How quenched	Water Line Pressure lbs. per sq. inch	Prop. Limit (Lbs. per square inch)	Yield Point (Lbs. per square inch)	Tensile Strength (Lbs. per square inch)	Breaking Strength	El. in 2 inches, Per Cent	Red. Area, Per Cent	Area under stress-strain curve, square inch	Izod impact, energy absorbed foot pounds
AR-1	"As Received"		13,500	.....	43,700	66,100	27.5	43.7	1.19	46.5, 40, 77 Average 54.5
AR-2	H_2O bath, 20° C.	none	13,500	.....	62,100	87,300	17.5	36.4	1.37	56, 40, 47 Average 47.7
AR-5	5% NaOH bath, 20° C.	none	14,000	.....	77,300	95,900	13.5	24.2	1.15	28, 43.5, 21 Average 30.8
AR-3	H_2O bath, 18° C.	20	13,500	.....	76,800	99,300	10.0	24.8	1.30	60.5, 66, 65.5 Average 64
AR-4[1]	H_2O bath, 17° C.	40	13,500	.....	79,800	117,500	13.5	26.2	.83	
AR-6	H_2O bath, 17° C.	85	16,500	.....	69,200	82,400	12.0	18.5	.54	63.5, 65, 62.5 Average 63.7

[1]Specimen split longitudinally at fracture.

Table XX
Mechanical Properties of Wrought Iron Quenched in Various Ways from 960 Degrees Cent. (1760 Degrees Fahr.)

Spec. No.	How quenched	Water Line Pressure lbs. per sq. inch	Prop. Limit	Yield Point	Tensile Strength	Breaking Strength	El. in 2 inches, Per Cent	Red. Area, Per Cent	Area under stress-strain curve, square inch	Izod impact, energy absorbed foot pounds
			Lbs. per square inch							
WI-1	"As Received"		11,000	37,250	54,500	87,200	32.0	47.5	1.79	44.5, 33.5, 46 Average 41.3
WI-2	H_2O bath, 18° C.	none	11,000	.....	56,000	88,600	24.5	44.5	1.51	41, 48.5, 50 Average 46.5
WI-3	H_2O spray, 18° C.	20	9,000	.....	64,000	61,500	16.0	34.2	1.09	31,[1] 73, 43 Average 49
WI-5	H_2O spray, 17° C.	85	11,000	.....	68,500	96,100	20.5	36.0	1.54	35, 47, 45.5 Average 42.5
WI-4	5% NaOH bath, 20° C.	none	11,000	.....	77,100	101,800	15.5	31.6	1.28	

[1]Large slag inclusion running longitudinally along one edge, higher reading obtained when this was parallel to direction of blow than when at right angles.

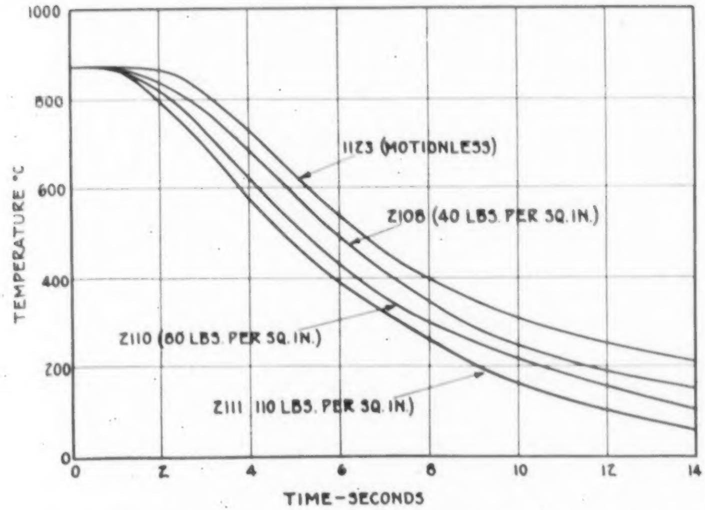

Fig. 70—Center Cooling Curves of 1-Inch Spheres Quenched in a Water Spray Under Different Pressures. Cooling in a Motionless Water Bath Given for Comparison. Coolant Temperatures 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

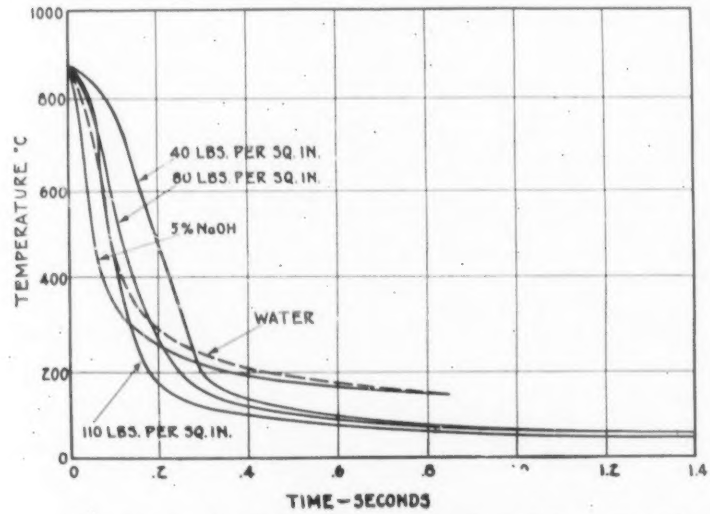

Fig. 71—Surface Cooling Curves of 1-Inch Spheres Quenched in a Water Spray Under Different Pressures. Cooling in Water and Sodium Hydroxide Baths, with Coolant Motion Approximately 3 Feet Per Second, Given for Comparison. Coolant Temperatures, 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

quite brittle and showed low ductility in the tension tests and low Izod impact numbers.

Ordinary water bath quenching of steel containing 0.07 per cent carbon raised the tensile strength from around 47,000 pounds per square inch to 67,000 pounds per square inch. Pressure spray quenching raised the strength still further to around 95,000 to

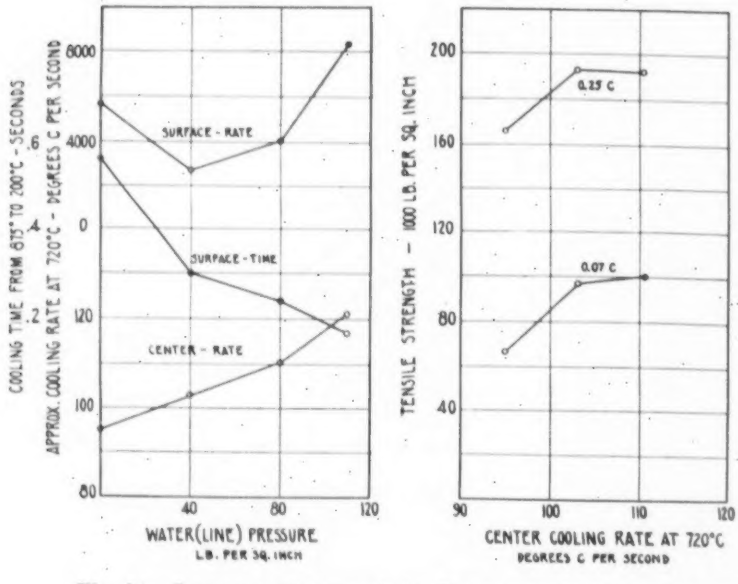

Fig. 72—Summary of Some of the Characteristics of the Cooling of 1-Inch Spheres Quenched in a Water Spray Under Different Pressures and the Relations Between Center Cooling Rates and Tensile Strengths of Low Carbon Steels.

110,000 pounds per square inch. Increased tensile strengths were also obtained in the American ingot iron and wrought iron but the increases were of smaller magnitude (Tables XIX and XX).

In the case of the ingot iron and wrought iron, quenching in a bath containing 5 per cent sodium hydroxide produced tensile properties comparable to those produced by the pressure spray quenching in water but there appeared to be a difference in the impact values in the two cases.

Time-temperature cooling curves taken at both center and surface of 1-inch spheres immersed in the water sprays are reproduced in Figs. 70 and 71 while the relation between center cooling rates and tensile strength of low carbon steels is given in Fig. 72.

If the variable initial periods, associated with difficulties in introducing the spheres into the pressure quench chamber, are neglected, it is seen that the speed of center cooling was very much higher with pressure spray quenching than with water bath quenching and increased generally with the line pressure.

This might lead to the conclusion that the surface cooling speeds were also much higher than in water bath quenching but examination of Figs. 71 and 72 shows that the cooling rates in the neighborhood of 700 degrees Cent. were not higher until the highest line pressure

(110 pounds per square inch) was used. On the other hand, the temperature range over which rapid cooling is observed was extended to much lower temperatures in pressure spray quenching than in water bath quenching. The continued rapid cooling to low temperatures means larger temperature gradients from center to surface and the maintenance of large gradients over a greater range of center cooling than in the case of the water bath. This should reduce appreciably the center cooling times and raise the center cooling speeds in the manner shown in Fig. 70.

As has been pointed out, rapid cooling is continued to somewhat lower temperatures in 5 per cent sodium hydroxide than in water baths. Rapid cooling continued to even lower temperatures in the case of the pressure spray and through the increased speeds of cooling at the interior of the body produced the high strengths shown in Fig. 72. However, the tensile strength is probably not solely a function of the cooling rates since with increase from 80 to 110 pounds per square inch water line pressure the rates of cooling increased at the center and the cooling times decreased but the changes in the strength of both the 0.07 per cent carbon and 0.25 per cent carbon steels were very small.

Water sprays, whether under relatively high or moderate pressures, provide one of the most effective of available means for securing uniformly rapid cooling. This is not due solely to the volume of liquid employed but is dependent upon the manner in which the liquid is brought into contact with the heated steel. With properly designed sprays the impingement of a relatively large number of small streams of liquid upon the surface of the steel should tend to break up, mechanically, the continuity of any gas films which tend to form and at the same time provide effective contact with more liquid per unit of steel surface. In other words sprays may be conceived to make more of a given volume of liquid do the useful work of cooling.

Either sprays or improved circulation in quenching baths are much better methods for increasing the speeds of cooling, when such effects are desired, than increases in the quenching temperature. The latter procedure frequently produces sufficient grain enlargement to reduce the notch toughness of the quenched steels and hence is not an ideal method to use, even though it may be useful in individual cases.

Chapter V

COOLANT TEMPERATURES

The effects of temperature on the cooling characteristics of commonly used liquids are known at least in a general way, but a number of matters still require elucidation. The practical importance of more complete knowledge of this subject becomes apparent when it is realized that much quenching is done in baths of limited capacity which may also not have well designed circulating or cooling systems and that with such conditions the average temperature of the bath may rise appreciably as the quenching of parts proceeds.

1. Center and Surface Cooling Curves

Figs. 73, 74 and 75 show the center and surface cooling of ½-inch steel cylinders immersed in water, No. 2 oil, 5 per cent sodium hydroxide and 5 per cent sodium chloride solutions at temperatures between 20 and approximately 100 degrees Cent. Data for the No. 1 oil are given in Fig. 81.

The highest coolant temperature, for water and the aqueous solutions, is given as 99.5 degrees Cent. The practice employed was to heat the bath to 100 degrees Cent., then remove the source of heat, and transfer the tank containing the heated liquid to the quenching apparatus previously described. Based on observations with the water baths, it was assumed that the average temperature drop in handling the different aqueous solutions was 0.5 degree Cent., and the specified temperature, 99.5 degrees Cent., merely indicates that the coolant temperature was slightly below the boiling point of water.

Figs. 73, 74, 75, 76 and 81 show that increase in the temperature lowered the cooling rates and increased the cooling times in water and the two aqueous solutions while opposite effects were produced in the center cooling by the two oils. The changes were small in the oils throughout the entire temperature range studied, (20 to 100 degrees Cent.) and were not as marked between 20 and 60 degrees Cent. in the water and aqueous solutions as between 60 and 99.5 degrees Cent. Also, the changes in cooling times with increase in the coolant temperature were smaller in 5 per cent sodium hydroxide than in 5 per cent sodium chloride and, with the exception of the range 80 to 99.5 degrees Cent., were smaller in 5 per cent sodium chloride than in tap water (Fig. 76).

The fact that temperature increase of the coolant affects the

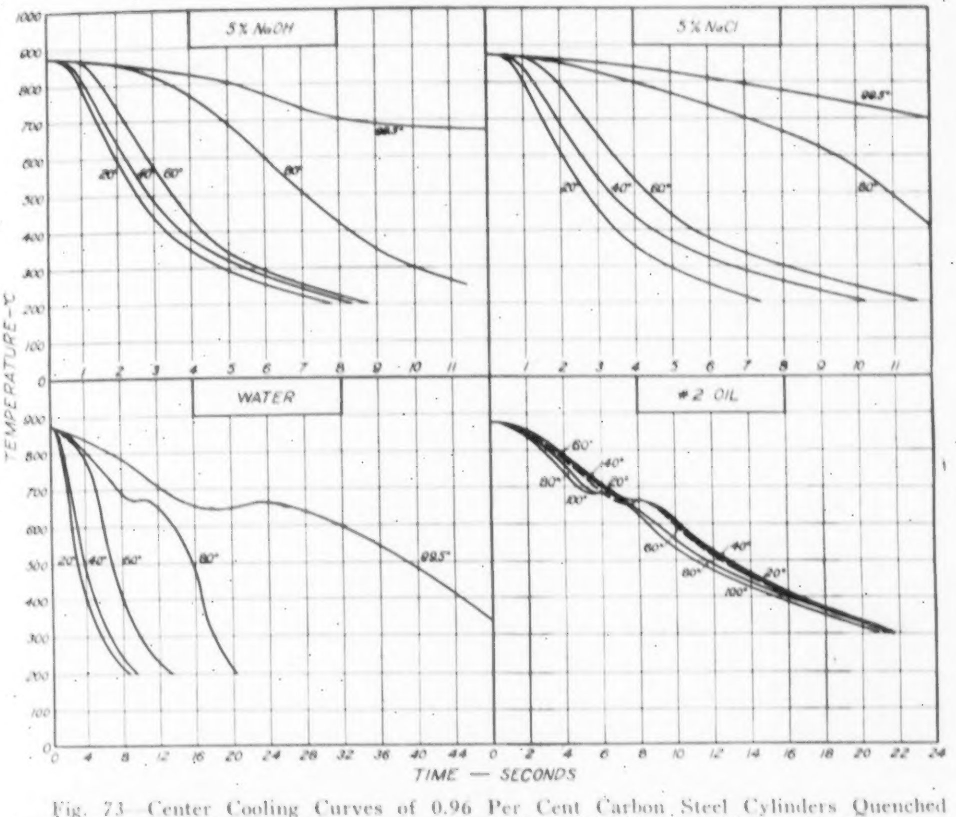

Fig. 73—Center Cooling Curves of 0.96 Per Cent Carbon Steel Cylinders Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Liquids at Different Temperatures. Coolant Motion was 3 Feet per Second; Cylinders were ½ Inch Diameter by 2 Inches Long. Each Carve is the Average of Two or Three Tests.

cooling in 5 per cent sodium hydroxide somewhat less than in water may be of advantage in practical heat treatment and probably contributes in an appreciable degree to the rapidity of cooling in the sodium hydroxide solutions. In all quenching operations, the liquid adjacent to the heated steel is raised in temperature even though it is only momentarily in contact with the heated metal surfaces. At least a part of the cooling of the steel is effected through contact with heated liquid and the vapors formed by, or released from it.

In liquids which normally decrease in cooling speeds with rise in temperature, a small temperature effect, as in the sodium hydroxide, means a tendency to maintain rapid cooling as well as ability to compensate for deficiencies in circulation which usually tend to raise the effective temperature of the quenching bath. From this viewpoint, the 5 per cent sodium hydroxide is a more desirable coolant than water.

Figs. 73 and 75 show that the center cooling of specimens im-

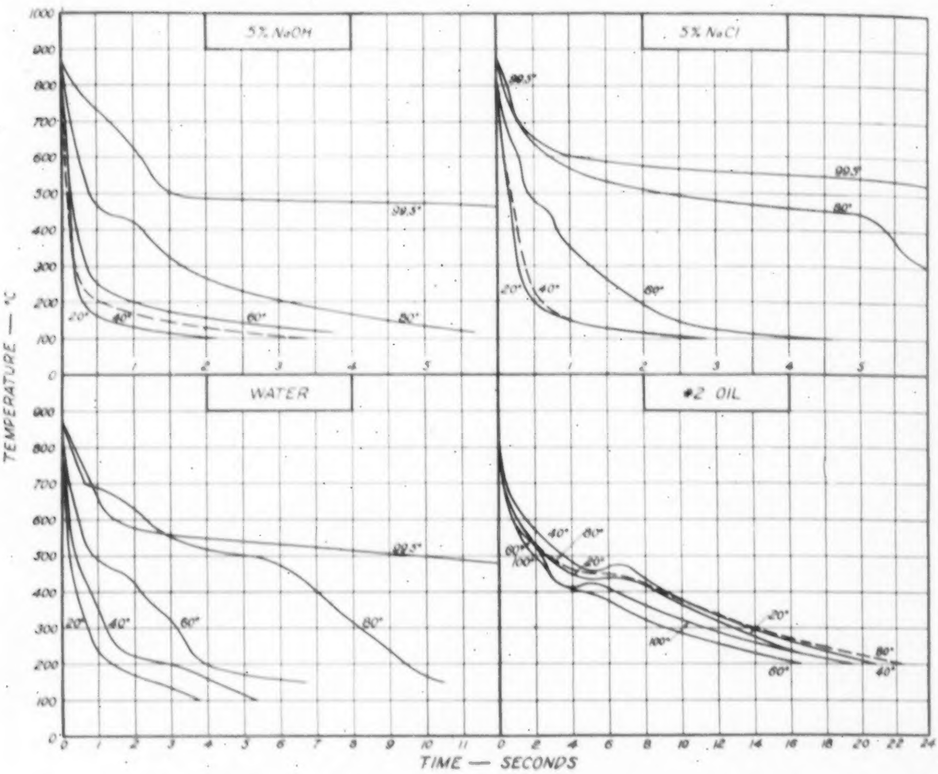

Fig. 74—Surface Cooling Curves of 0.96 Per Cent Carbon Steel Cylinders Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Liquids at Different Temperatures. Coolant Motion was 3 Feet per Second; Cylinders were ½ Inch Diameter by 2 Inches Long. Each Curve is the Average of Two or Three Tests at a Point Meeting the Direct Flow of the Liquid.

mersed in water at 80 degrees or 99.5 degrees Cent. was somewhat more rapid at low temperatures around 200 to 300 degrees Cent. (390 to 570 degrees Fahr.) than at high temperatures around 700 to 800 degrees Cent. (1290 to 1470 degrees Fahr.). A similar condition was observed in 5 per cent sodium hydroxide at 99.5 degrees Cent. but not at 80 degrees Cent. nor in 5 per cent sodium chloride at 80 or 99.5 degrees Cent.; in the last three cases, the cooling rates were quite regular throughout the temperature range, 850 to 200 degrees Cent. (1560 to 390 degrees Fahr.). In general, these center cooling characteristics were a reflection of the conditions at the surface although the surface cooling became somewhat more irregular as the temperature of the aqueous solutions approached the boiling point of water.

Rapid cooling of the steel specimens at low temperatures in hot water and the hot aqueous solutions is well recognized and is usually considered to be disadvantageous since steels are least able to deform

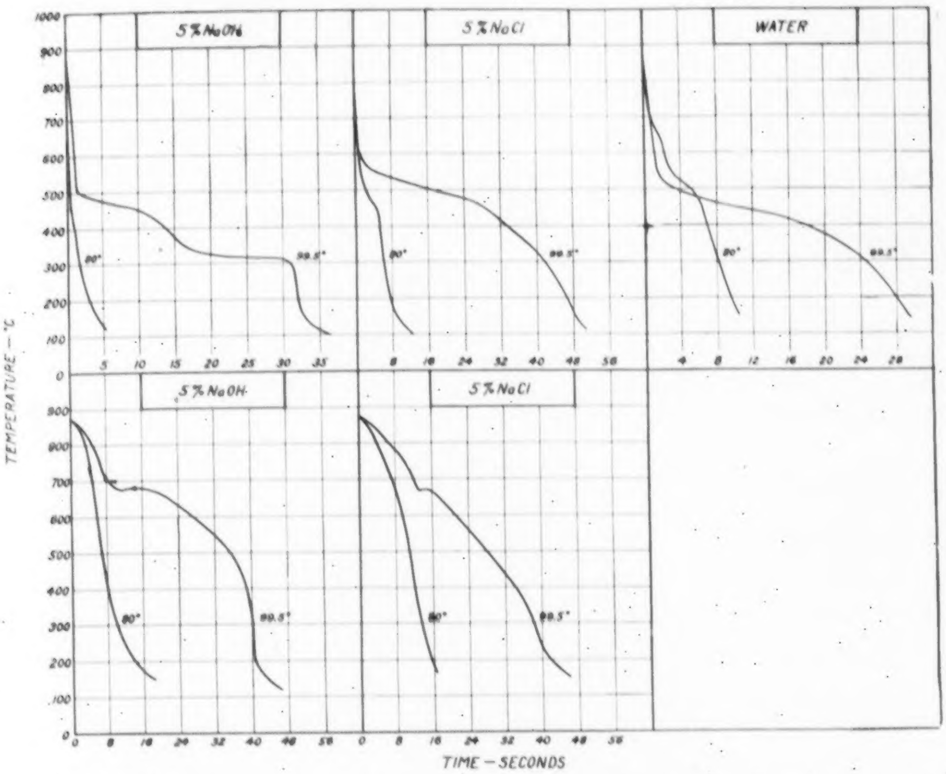

Fig. 75—Replot of Center and Surface Cooling Curves in Liquids at 80 and 99.5 Degrees Cent. (175 and 210 Degrees Fahr.) Shown in Part in Figs. 73 and 74. Surface Cooling Shown in Top Row, Center Cooling in Bottom Row.

without cracking at temperatures around 300 degrees Cent. (570 degrees Fahr.) and so relieve the stresses accompanying the volume changes in hardening.

However, it is difficult to see how the rapid cooling in hot water could, by itself, cause great difficulty since the cooling rates are less than those obtaining in cold water, cold brines and sodium hydroxide solutions in which such difficulties are not important enough to prohibit their use in practical heat treatment. It seems more probable that the danger of cracking in hot water quenching is due to *lack of uniform conditions over the surface of the steel* during fairly rapid cooling at low temperatures. Evidence of non-uniformity was shown in the original records of the cooling curves, but a much better picture of this situation was obtained by watching and listening to the actual quenching operation.

As the initial temperature of the water bath is increased, somewhat less heat must be taken from the steel to form steam, and it

Table XXI

Comparisons of Hot Water or Hot Aqueous Solutions with Oils at Atmospheric Temperatures in Cooling High Carbon Steel Cylinders from 875 Degrees Cent. (1605 Degrees Fahr.)

Coolant	Approximate time, in seconds, to cool from 875°C (1605°F) to designated temperature (1)					
	800°C 1470°F	700°C 1290°F	600°C 1110°F	500°C 930°F	400°C 750°F	200°C 390°F
			At Center			
Water at 20°C	1.4	2.0	2.6	3.2	4.1	8.6
5% NaOH at 60°C	1.6	2.2	2.8	3.5	4.3	8.8
Water at 40°C	1.6	2.3	3.0	3.9	4.8	9.4
5% NaCl at 60°C	2.0	2.8	3.5	4.4	5.5	11.8
5% NaOH at 80°C	3.4	4.8	6.0	7.1	8.3	14.1
No. 1 oil at 20°C	2.9	4.9	7.5	11.1	15.6	28.8
5% NaCl at 80°C	3.9	7.1	9.4	10.9	12.1	16.0
No. 2 oil at 20°C	3.6	6.2	8.8	12.4	16.5	29.7
			At Surface			
Water at 20°C	0.02	0.07	0.12	0.21	0.38	1.2
5% NaOH at 60°C	0.03	0.08	0.11	0.15	0.24	1.0
Water at 40°C	0.06	0.14	0.22	0.34	0.56	2.0
5% NaCl at 60°C	0.03	0.11	0.22	0.38	0.62	1.8
5% NaOH at 80°C	0.07	0.15	0.25	0.40	0.72	3.1
No. 1 oil at 20°C	0.07	0.15	0.34	0.96	2.5	14.7
5% NaCl at 80°C	0.10	0.30	0.70	1.48	2.78	7.0
No. 2 oil at 20°C	0.09	0.27	0.89	2.4	5.5	19.3

(1) Heat effects of transformations disregarded.

is not unreasonable to assume that more steam will come in contact with, or become attached to, the surfaces of the metal in a given time. As has already been shown such conditions promote non-uniform cooling since the action at the contact surfaces between the metal and the coolant, or their products, is probably made up primarily of rapidly repeated cycles of steam generation, momentary attachment of steam to the metal surface and its removal.

In any case, hot water at temperatures in the neighborhood of 80 to 100 degrees Cent. is not a good quenching medium under ordinary conditions. Where somewhat slower cooling is desired than can be secured in water at 20 degrees Cent. and the oils are too slow, possibilities may be found in hot brines and, more particularly, in the hot sodium hydroxide solutions. The center cooling curves were generally smooth, without abrupt changes in direction, for water at 40 degrees Cent. and 5 per cent sodium hydroxide at 60 to 80 degrees Cent. Also cooling times were obtained in the hot sodium hydroxide solutions which were between water and oils at ordinary temperatures, as is shown in Table XXI.

In examining the data in Table XXI it should be kept in mind that the cooling curves obtained in aqueous solutions have a some-

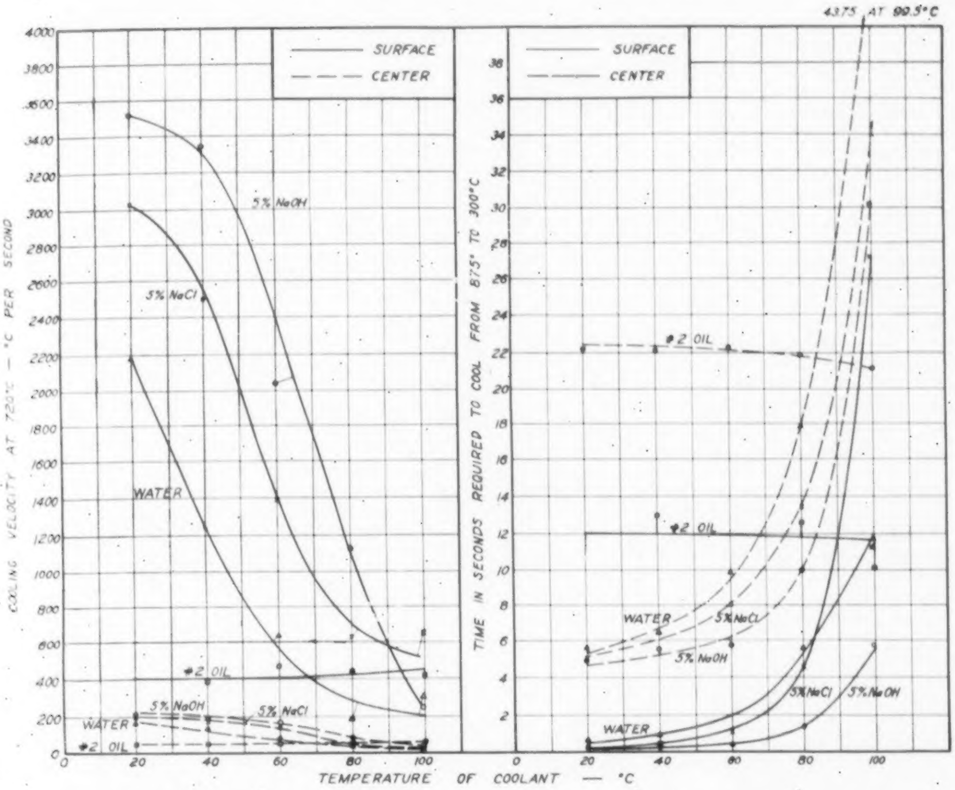

Fig. 76—Effect of Temperature on Center and Surface Cooling Times and Rates in Different Liquids. This is a Summary of the Curves Shown in Figs. 73, 74 and 75.

what different form than those in the oils, and for this reason short cooling times at high temperatures are not necessarily concomitant with short cooling times to low temperatures. The cooling at low temperatures in oils is generally slower than that in aqueous solutions as is shown in Figs. 73, 74 and 75, and Table XXI, and the temperature of the coolant which may give the desired results will depend upon the steel under treatment, its size and shape, etc.

2. Hardness and Structures Produced by the Hot Aqueous Solutions

The effects of temperature of the coolant on the hardness and structures produced in ½ inch diameter by 2-inch cylinders of 0.96 per cent carbon steel are shown, together with cooling times, in Figs. 77 to 81 inclusive. Fig. 82 contains direct comparisons of the Rockwell hardness produced by quenching in the different liquids at different temperatures.

The fully hardened 0.96 per cent carbon steel, having a marten-

sitic structure free from readily detectable areas of troostite, had a Rockwell "C" scale hardness of 63 to 65. This hardness was not attained at surface or center when the steel was quenched in either of the two oils, but was obtained at the center with water up to 60 degrees Cent., 5 per cent sodium chloride up to 70 degrees Cent. and 5 per cent sodium hydroxide up to 80 degrees Cent. (Fig. 82). With increase above the designated temperatures the hardness dropped appreciably and rapidly.

While water at 60 degrees Cent., 5 per cent sodium chloride at 70 degrees Cent. and 5 per cent sodium hydroxide at 80 degrees Cent. produced a Rockwell hardness equivalent to that obtained from the same coolants at atmospheric temperatures, there were appreciable differences in the structures of the quenched steels. In general, as the temperature of the coolant was increased, the structure changed from martensite (plus austenite) to martensite with increasing amounts of primary troostite and finally to troosto-sorbite and sorbite with some evidence of lamellar pearlite.

As has been indicated already the effects of temperature of the coolant on the cooling of the steels quenched in oils were small but opposite to the effects observed in water and the aqueous solutions. The cooling was slightly faster in the No. 2 oil at 100 degrees Cent. than at 20 degrees Cent. (Figs. 73 and 74) and this was confirmed by the hardness tests reported in Fig. 80. A similar result was shown in the No. 1 oil (Fig. 81) but the changes were somewhat smaller. However, not all oils show increased speeds of cooling with increase in temperature[30] as in the two cases cited.

3. Liquids with Graded Cooling Speeds

Present day hardening practice is based quite largely upon the use of oils, water and the more rapid aqueous solutions such as sodium chloride brines, sodium hydroxide solutions, and water sprays at ordinary temperatures. There is a large gap between the cooling rates obtained in the customary quenching oils and in water, and this is now usually taken care of by tempering subsequent to hardening or by interrupted quenching. Such procedure is entirely satisfactory for many practical purposes, but simplification and economy and possibly also technical advantages would result if coolants were

[30]J. A. Mathews and H. J. Stagg; "Factors in Hardening Tool Steel." *Transactions*, American Society of Mechanical Engineers, Vol. 36, 1914, p. 845.

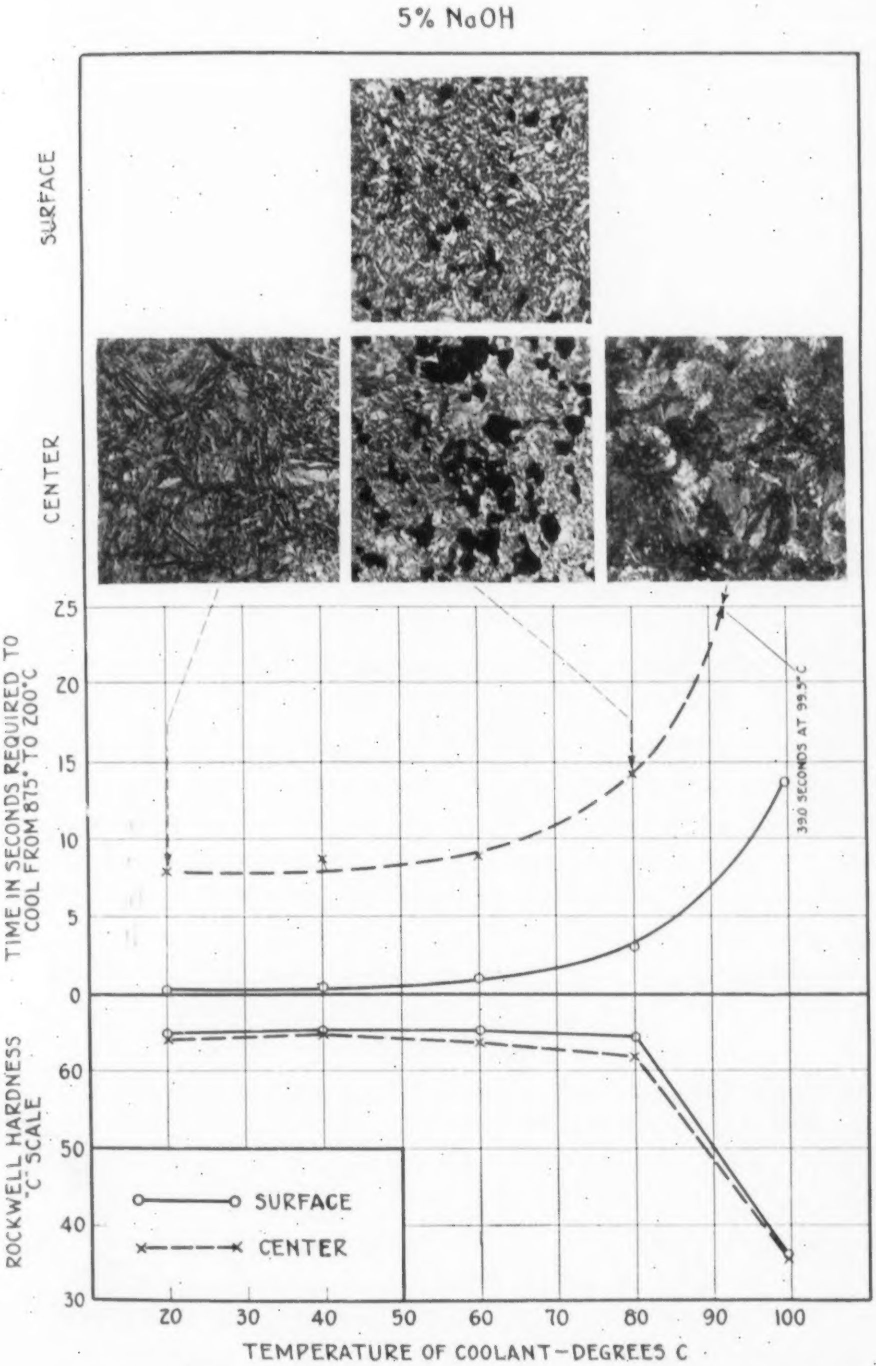

Fig. 77—Hardness, Cooling Times and Structure at the Center and Surface of 0.96 Per Cent Carbon Steel Cylinders Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into 5 Per Cent Sodium Hydroxide at Different Temperatures. Coolant Motion 3 Feet per Second; Cylinders ½ Inch Diameter by 2 Inches Long. Microstructures Originally × 500, Reduced 60 Per Cent in Printing. Samples Etched in 2 Per Cent Nitiric Acid in Alcohol. Where Surface Structures Resembled Those at the Center Only the Latter are Given.

Table XXII
List of Liquids Given in Order of Decrease in Cooling Speeds

Liquid and Temperature	Cooling time from 875° to 200°C (1) in seconds for Surface	Center
MORE RAPID THAN WATER		
5% NaOH at 20°C	0.31	7.8
5% NaCl at 20° C	0.48	7.4
WATER AT 20°C	1.2	8.6
RATES BETWEEN WATER AND OILS		
5%. NaOH at 60°C	1.03	8.8
5% NaCl at 60°C	1.8	11.8
Water at 60°C	3.2	13.4
5% NaOH at 80°C	3.1	14.2
RATES CLOSE TO OR OF OILS		
5% NaOH at 85°C	{5.0}	{17.0}
5% NaOH at 90°C	{7.0}	{22.0}
No. 1 oil at 20°C	14.7	28.8
No. 2 oil at 20°C	19.3	29.7

(1) For 0.96 per cent carbon steel cylinders ½ inch diameter by 2 inches long; liquid moving at 3 ft. per second.

Bracketed values estimated by interpolation.

available to provide a more closely graded set of cooling characteristics.

The practical solution of this problem is not solely one of obtaining certain prescribed cooling rates since general availability and cost, permanence, safety from the standpoint of the operators, properties affecting adherence to the quenched metals which in turn affect the losses from the bath and cleaning costs, as well as other factors, should be given consideration. Nevertheless, one of the principal requirements is meeting certain prescribed cooling rates.

The liquids discussed in this chapter offer a graded set of cooling rates from those of water and the more rapid aqueous solutions at atmospheric temperatures to those of the customary oils and in this respect they are of interest although only some would be classed as good or useful coolants from the viewpoint of practical heat treatment.

The most promising group, selected from the liquids considered, are given in Table XXII in order of decrease in the speeds, or increase in the times, of cooling. The order given is correct insofar as the hardness, structures and center cooling times from 875 to 200 degrees Cent. (1605 to 390 degrees Fahr.) are concerned but not necessarily so for the cooling through other temperature ranges since the cooling curves of the different liquids do not all have the same form.

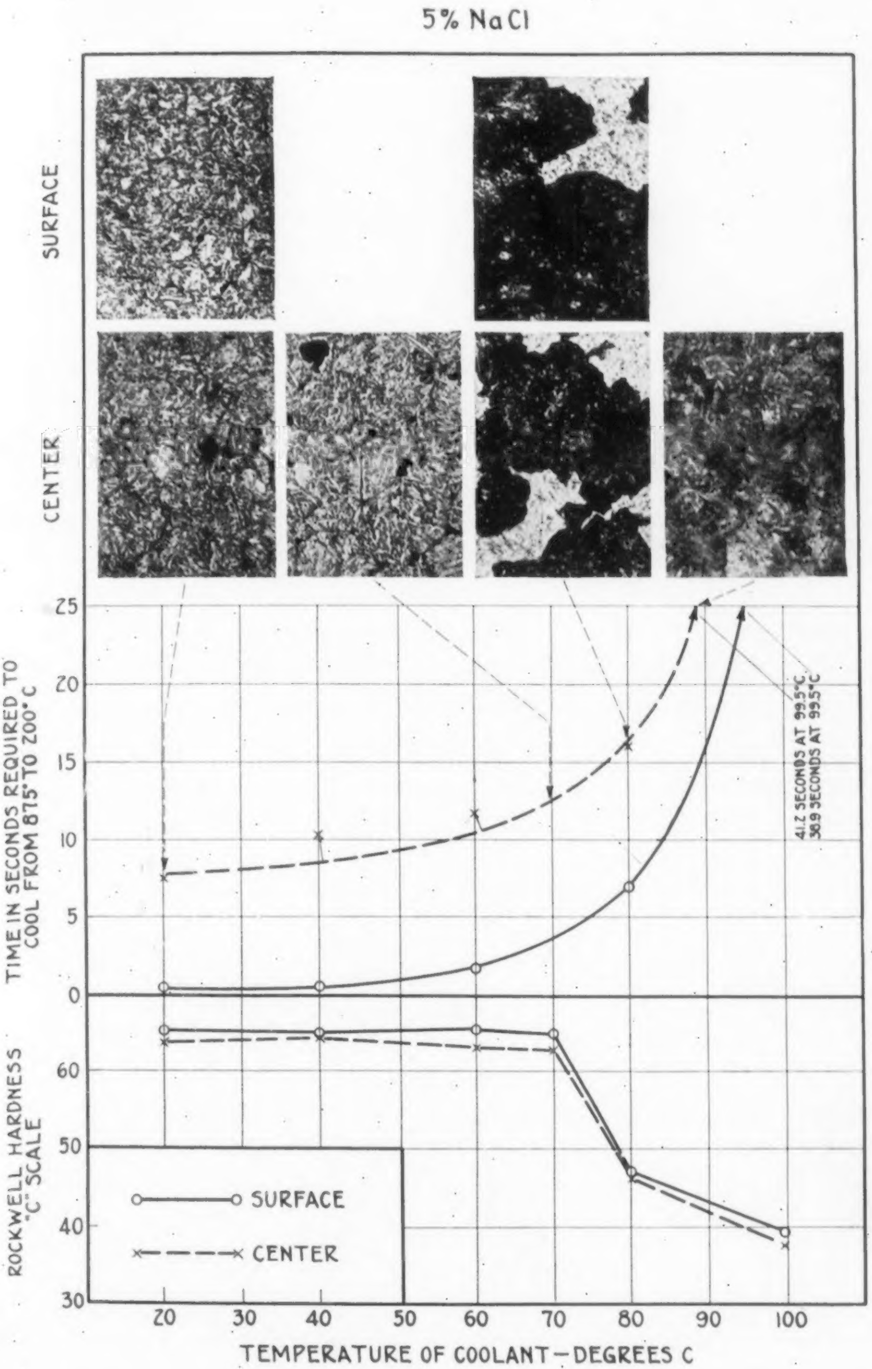

Fig. 78—Hardness, Cooling Times and Structure at the Center and Surface of 0.96 Per Cent Carbon Steel Cylinders Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into 5 Per Cent Sodium Chloride at Different Temperatures. Coolant Motion 3 Feet per Second; Cylinders ½ Inch Diameter by 2 Inches Long. Microstructures Originally × 500, Reduced 60 Per Cent in Printing. Samples Etched in 2 Per Cent Nitric Acid in Alcohol. Where Surface Structures Resembled Those at the Center Only the Latter are Given.

A list based on somewhat closer gradations can be prepared from the data in Figs. 73 to 82 inclusive and substitutions can be made in a number of cases, but in Table XXII coolants showing the strongest tendencies toward irregular results have been omitted; only those were chosen in which smooth center cooling curves were obtained with fairly uniform slopes from 850 to 200 or 300 degrees Cent. (1560 to 390 or 570 degrees Fahr.)

The corrosive nature of the hot sodium hydroxide solutions and the hot sodium chloride brines is at the same time an advantage and a disadvantage. These solutions are not easy to handle industrially from the standpoint of either equipment or operators, but the quenched steels are relatively free from heavy scale, and with bath temperatures of 60 to 80 degrees Cent. or less, will often come out bright. This denotes active scale removal during the quench, an effect which tends to promote uniformity in the results obtained.

Observations during the experiments clearly indicated that as the temperature of the sodium chloride and hydroxide solutions approached the boiling point of water, there was a decided decrease in the uniformity of the conditions at the contact surfaces of the steel and the coolant. However, it should be kept in mind that all the experiments were made with low coolant velocities and that if better circulation were provided more uniform conditions could be expected. Liquids unsatisfactory at low rates of motion might become satisfactory at higher rates of motion.

4. Tensile Properties Produced by the Hot Aqueous Solutions

Two sets of tensile test bars were quenched in some of the hot aqueous solutions to give additional comparisons with water and the No. 2 oil at atmospheric temperatures. The first set was prepared from an oil hardening nickel-chromium steel while the second comprised specimens of 0.45 per cent carbon steel. The results of the tensile tests are summarized in Tables XXIII and XXIV.

In the case of the nickel-chromium steel (Table XXIII) somewhat better uniformity was obtained in the two oil-quenched samples than in those which were quenched in water at 70 degrees Cent. but the best combination of strength and ductility was obtained in samples quenched in 5 per cent sodium hydroxide at 80 degrees Cent. The results obtained with 5 per cent sodium chloride at 80 degrees Cent.

Table XXIII

Tensile Properties of a Cr-Ni Steel Quenched from 840 Degrees Cent. (1550 Degrees Fahr.) into Different Liquids Moving at 3 Feet Per Second[1]

(C 0.23, Cr 1.06, Ni 1.64, P 0.021, S 0.020)

Specimen No.	Coolant	Coolant Temp. °C.	Tensile Strength lbs./in.²	Breaking Strength[2] lbs./in.²	Elongation in 2 inches per cent	Reduction of Area per cent	Type of Fracture
5C-1	No. 2 oil	20	225,600	334,200	12.5	47.2	7/8 cup and cone—fibrous structure.
5C-2	No. 2 oil	22	225,000	321,400	12.0	44.1	5/8 cup and cone—fibrous structure.
Ave.			225,300	327,800	12.3	45.7	
5C-3	Water	70	246,000	308,000	9.0	33.1	7/8 cup and cone (deep elliptical)—fibrous structure.
5C-4	Water	71	232,400	358,000	12.0	49.0	Full cup and cone—fibrous structure.
Ave.			239,200	333,000	10.5	41.1	
5C-5	5% NaCl	80	232,800	294,500	9.5	26.2	1/2 cup and cone (deep elliptical)—fibrous.
5C-6	5% NaCl	81	230,900	278,000	9.0	25.1	1/2 cup and cone (deep)—fibrous structure.
Ave.			231,900	286,300	9.3	25.7	
5C-7	5% NaOH	80	236,000	369,000	13.0	51.1	5/8 cup and cone—fibrous structure.
5C-8	5% NaOH	80	235,500	361,500	13.0	50.0	5/8 cup and cone—fibrous structure.
Ave.			235,800	365,300	13.0	50.6	
5C-9	5% NaOH	85	232,500	313,000	10.0	34.7	1/2 thin cup and cone—fibrous structure.
5C-10	5% NaOH	85	230,800	301,000	9.5	30.2	5/8 thin cup and cone—fibrous structure.
Ave.			231,700	307,000	9.8	32.5	
5C-11	5% NaOH	90	200,700	245,000	7.5	20.0	Sharp, rather flat break—fibrous structure.
5C-12	5% NaOH	90	198,800	243,500	6.5	20.0	Sharp, flat break—fibrous structure.
Ave.			199,800	244,300	7.0	20.0	

[1]Specimens were held 30 minutes at temperature before quenching.

[2]The load at fracture divided by the area of the fractured section.

Table XXIV

Tensile Properties of a 0.44 Per Cent Carbon Steel Quenched from 815 Degrees Cent. (1500 Degrees Fahr.) into Different Liquids Moving at 3 Feet Per Second[1]

(C 0.44, Mn 0.81, P 0.025, S 0.022)

Specimen No.	Coolant	Coolant Temp. °C.	Tensile Strength lbs./in.²	Breaking Strength[2] lbs./in.²	Elongation in 2 inches per cent	Reduction of Area per cent	Type of Fracture
7A-1	No. 2 oil	18	128,500	135,200	1.5	4.7	Fine crystalline structure—sharp break.
7A-2	No. 2 oil	21	148,500	158,000	1.0	5.9	Fine crystalline structure—sharp break.
Ave.			138,500	146,600	1.3	5.3	
7A-3	Water	70	106,500	111,500 }*	3.0	4.5	Fine crystalline structure—sharp break.
7A-4	Water	70	127,200	198,800 }	14.0	54.8	7/8 deep cup and cone—fibrous structure.
Ave.			116,900	155,200	8.5	29.7	
7A-5	5% NaCl	79	119,200	189,300	17.0	47.2	5/8 deep cup and cone—fibrous structure.
7A-6	5% NaCl	81	118,500	201,000	17.5	51.7	5/8 deep cup and cone—fibrous structure.
Ave.			118,900	195,200	17.3	49.5	
7A-7	5% NaOH	80 }	Both specimens cracked in quenching.				Very fine crystalline structure—sharp break.
7A-8	5% NaOH	80 }					Very fine crystalline structure—rather sharp break.
7A-9	5% NaOH	85	77,500	80,800	1.0	4.0	Very fine crystalline structure—sharp break.
7A-10	5% NaOH	85	95,700	98,700	1.0	2.8	Very fine crystalline structure—rather sharp break.
Ave.			86,600	89,800	1.0	3.4	
7A-11	5% NaOH	90	114,700	200,000	20.5	55.3	3/4 cup and cone—fibrous structure.
7A-12	5% NaOH	90	114,700	195,600	20.5	54.2	5/8 cup and cone—fibrous structure.
Ave.			114,700	197,800	20.5	54.8	

[1]Specimens were held 30 minutes at temperature before quenching.
[2]The load at fracture divided by the area of the fractured section.
*Instability as referred to in text.

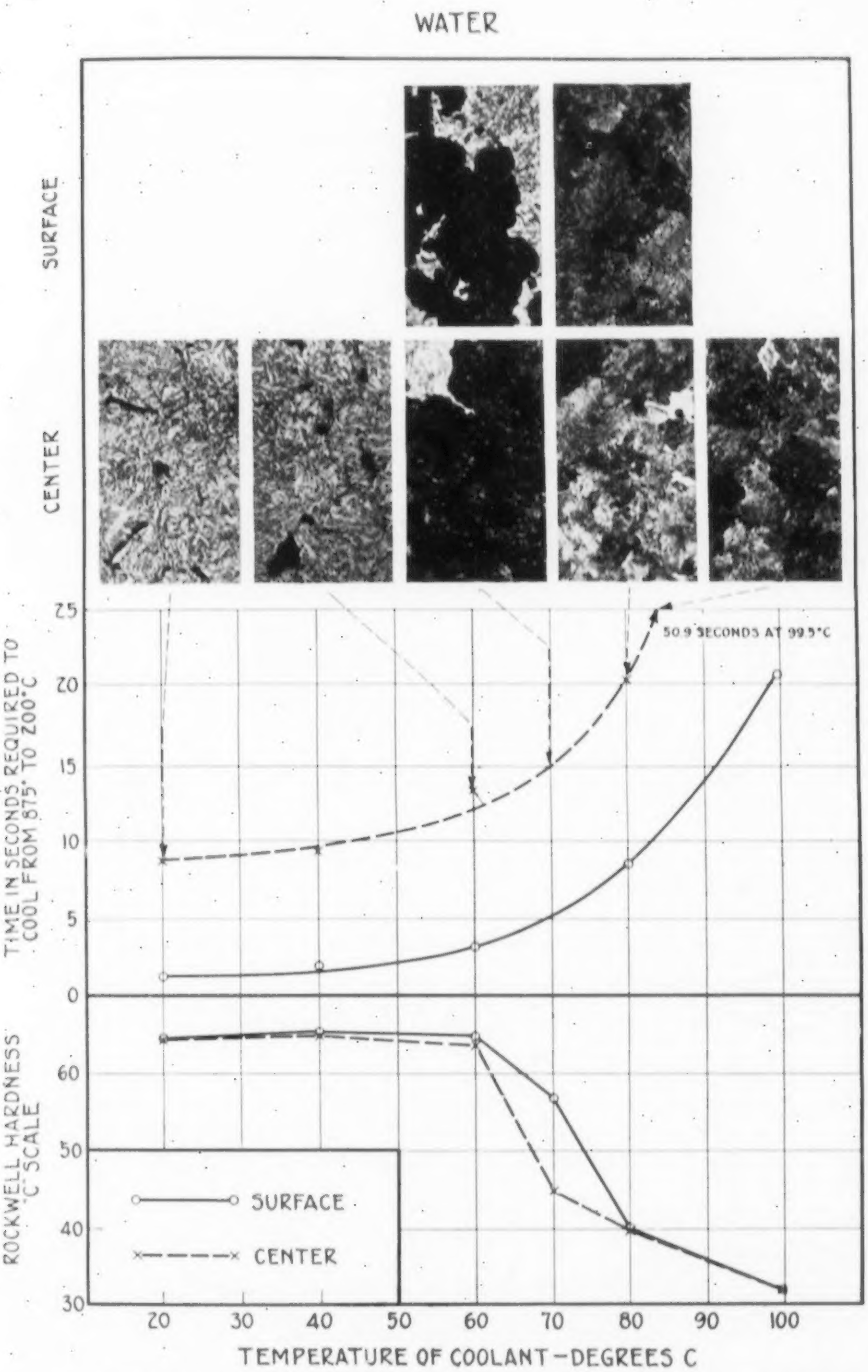

Fig. 79—Hardness, Cooling Times and Structure at the Center and Surface of 0.96 Per Cent Carbon Steel Cylinders Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at Different Temperatures. Coolant Motion 3 Feet per Second; Cylinders ½ Inch Diameter by 2 Inches Long. Microstructures Originally × 500, Reduced 60 Per Cent in Printing. Samples Etched in 2 Per Cent Nitric Acid in Alcohol. Where Surface Structures Resembled Those at the Center Only the Latter are Given.

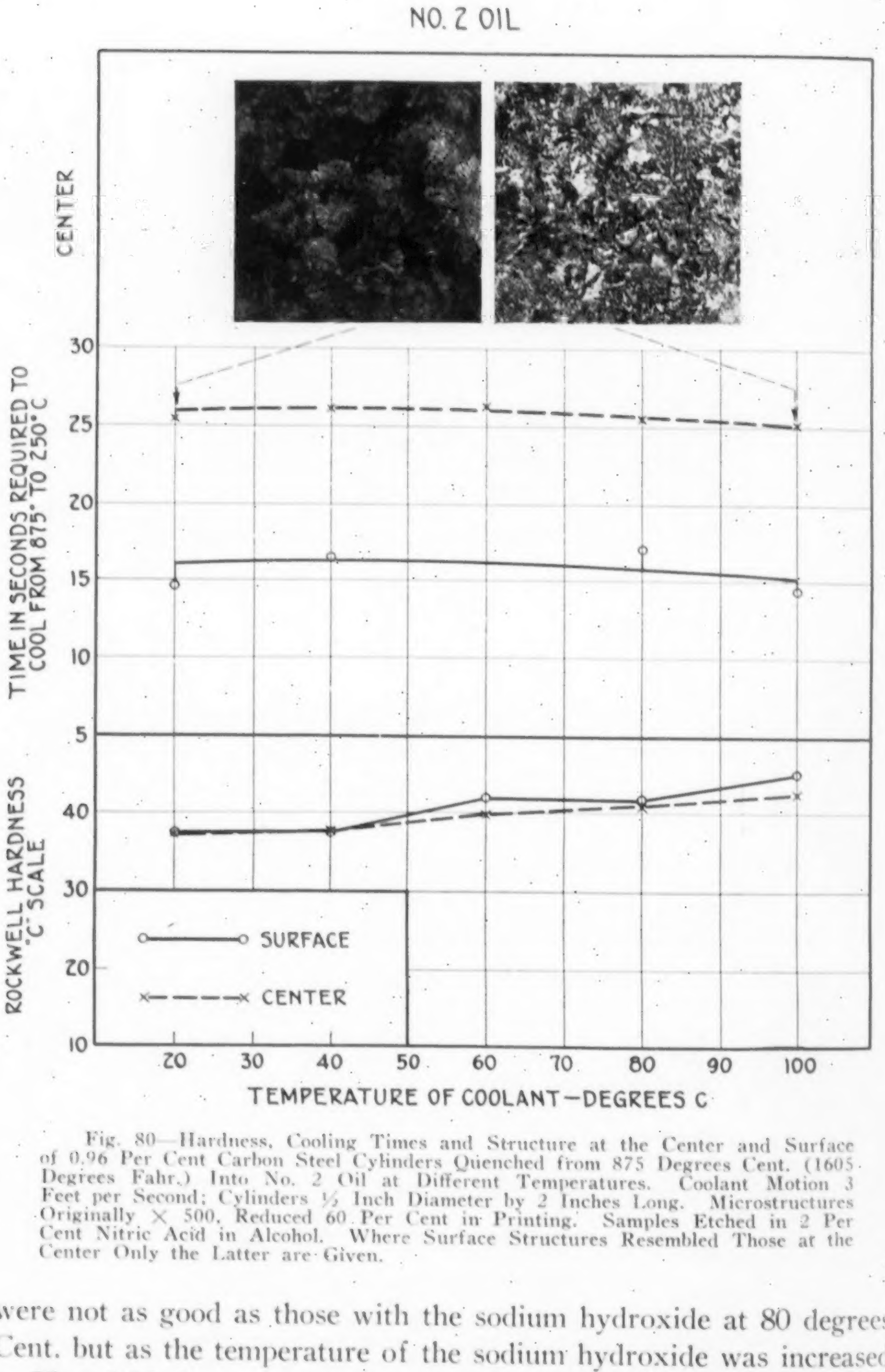

Fig. 80—Hardness, Cooling Times and Structure at the Center and Surface of 0.96 Per Cent Carbon Steel Cylinders Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into No. 2 Oil at Different Temperatures. Coolant Motion 3 Feet per Second; Cylinders ½ Inch Diameter by 2 Inches Long. Microstructures Originally × 500, Reduced 60 Per Cent in Printing. Samples Etched in 2 Per Cent Nitric Acid in Alcohol. Where Surface Structures Resembled Those at the Center Only the Latter are Given.

were not as good as those with the sodium hydroxide at 80 degrees Cent. but as the temperature of the sodium hydroxide was increased to 85 and 90 degrees Cent. there was a decrease in both the strength and ductility.

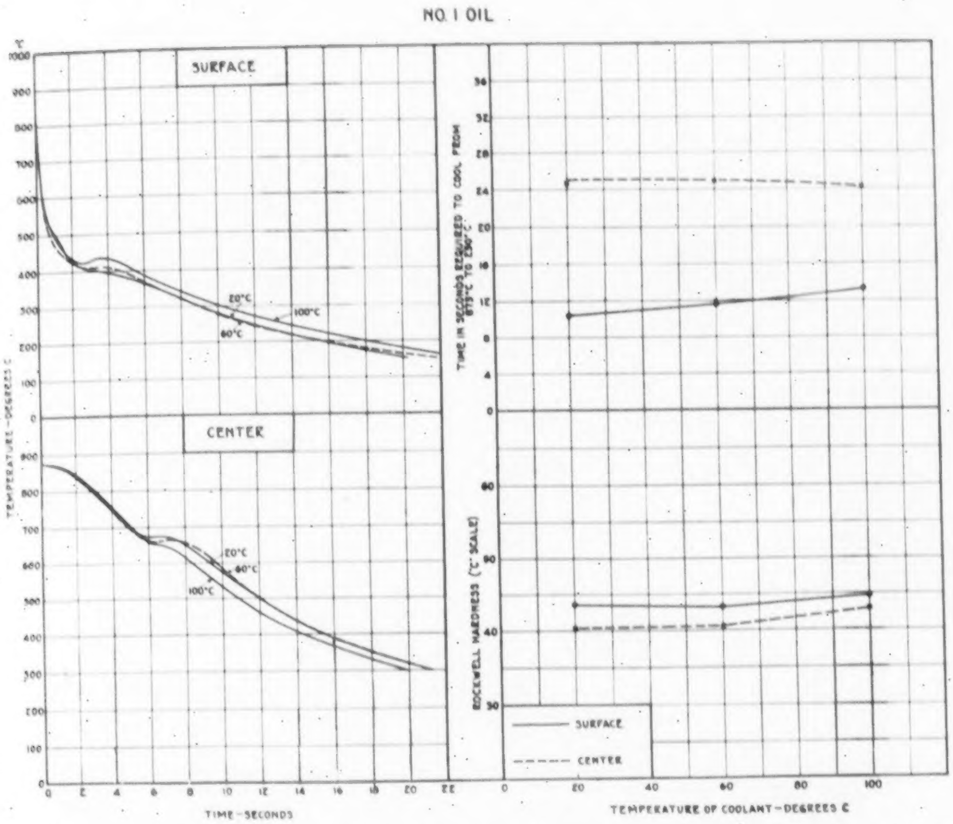

Fig. 81—Cooling Curves, Cooling Times and Hardness at Center and Surface of 0.96 Per Cent Carbon Steel Cylinders Quenched in No. 1 Oil at Different Temperatures. Coolant Motion 3 Feet per Second; Cylinders ½ Inch Diameter by 2 Inches Long.

The specimens of 0.45 per cent carbon steel cracked when quenched in the 5 per cent sodium hydroxide at 80 degrees Cent. (Table XXIV). Poor mechanical properties were obtained in the same liquid at 85 degrees Cent. but when the temperature was raised to 90 degrees Cent. an excellent combination of strength and ductility was obtained. Good strength, elongation and reduction of area were also obtained in 5 per cent sodium chloride at 80 degrees Cent. but erratic results were obtained in water at 70 degrees Cent. Hankins and Ford[31] tried unsuccessfully to quench 18-inch tensile specimens, 3 inches wide and ⅜ inch thick of a 0.60 per cent carbon steel from 800 degrees Cent. (1470 degrees Fahr.) into water at 50 degrees Cent. without cracking after being successful with 3 and 6-inch plates of the same width and thickness.

[31] G. A. Hankins and G. W. Ford, "The Mechanical and Metallurgical Properties of Spring Steels as Revealed by Laboratory Tests." *Journal*, British Iron and Steel Institute, Vol. 119, 1929, p. 217.

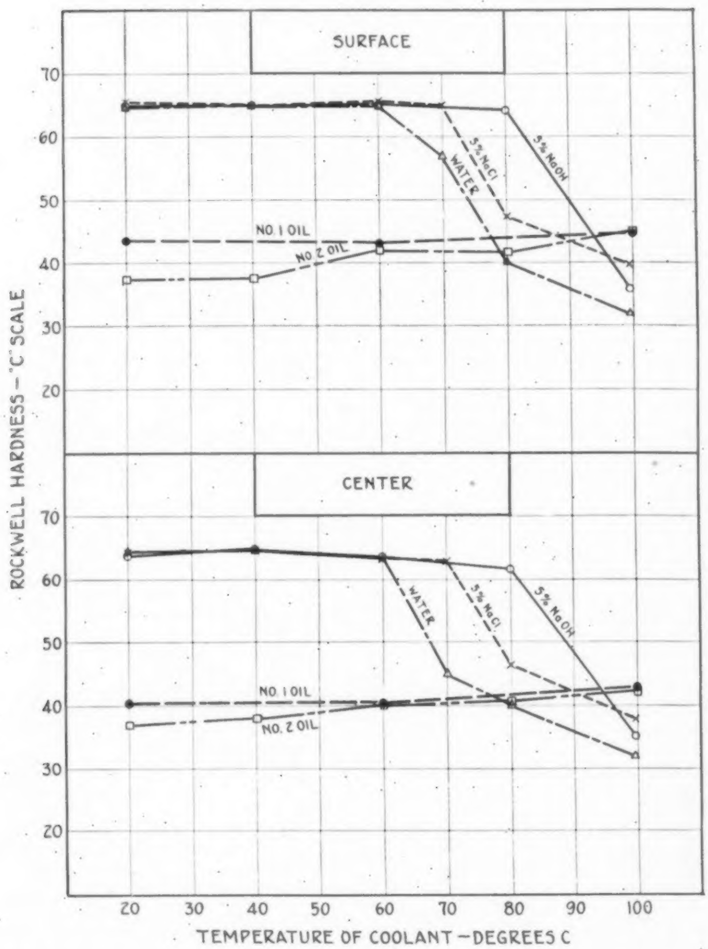

Fig. 82—Surface and Center Hardnesses of the 0.96 Per Cent Carbon Steel Cylinders Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Different Liquids at Different Temperatures. Coolant Motion 3 Feet per Second; Cylinders, ½ Inch Diameter by 2 Inches Long.

The structures of some of the tensile test specimens are shown in Figs. 83 and 84. The No. 2 oil at 20 degrees Cent. and the 5 per cent sodium hydroxide at 90 degrees Cent. produced a troosto-sorbitic structure in the 0.45 per cent carbon steel while the 5 per cent sodium chloride at 80 degrees Cent. and the 5 per cent sodium hydroxide at 85 degrees Cent. produced a martensitic structure containing appreciable proportions of troostite. The differences in ductility and tensile strength in samples 7A-9 and 7A-5, Fig. 83, were probably due in part to differences in the degree of tempering of the martensite, to differences in the proportions of troostite present and

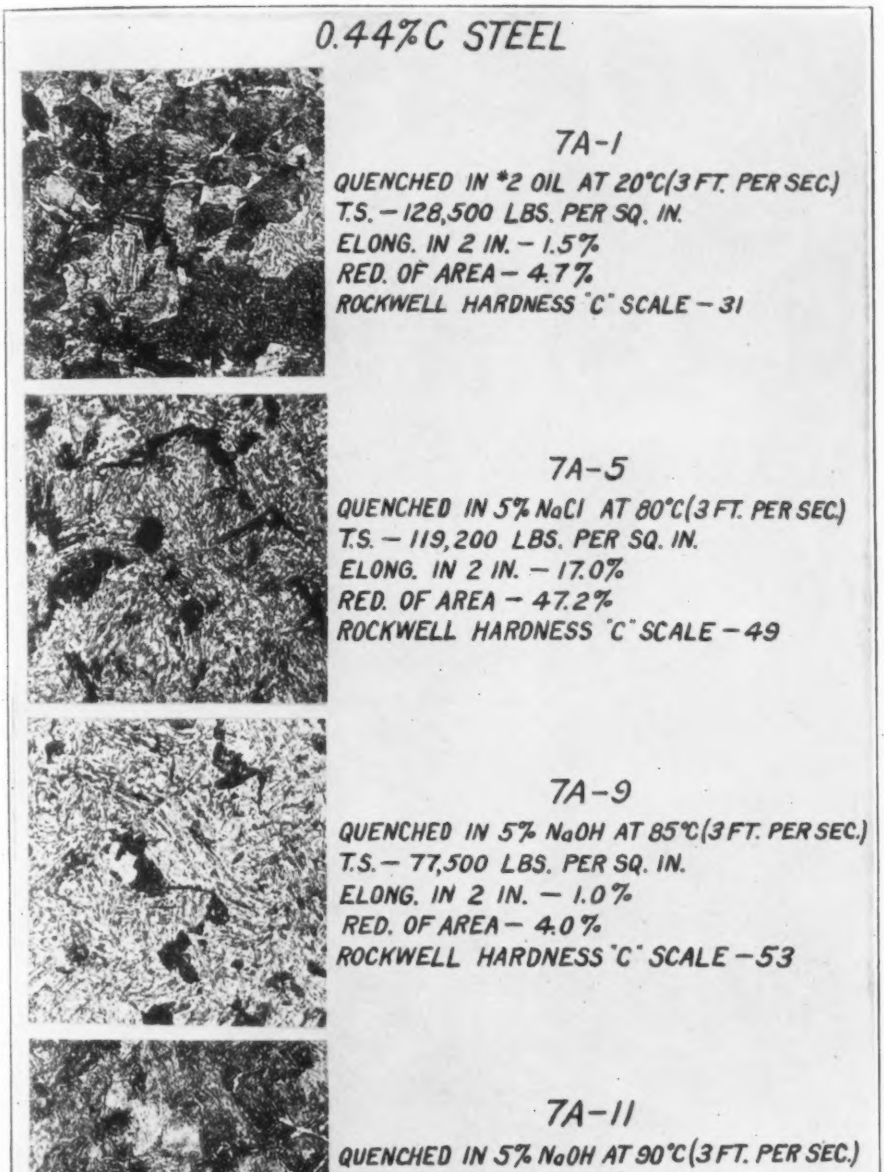

Fig. 83—Microstructures and Physical Properties of Some of the Tensile Specimens Tested, Summarized in Table V. Microstructures which were Taken at Center of the Tensile Specimens Originally × 500, Reduced 46 Per Cent in Printing. Samples Etched in 2 Per Cent Nitric Acid in Alcohol.

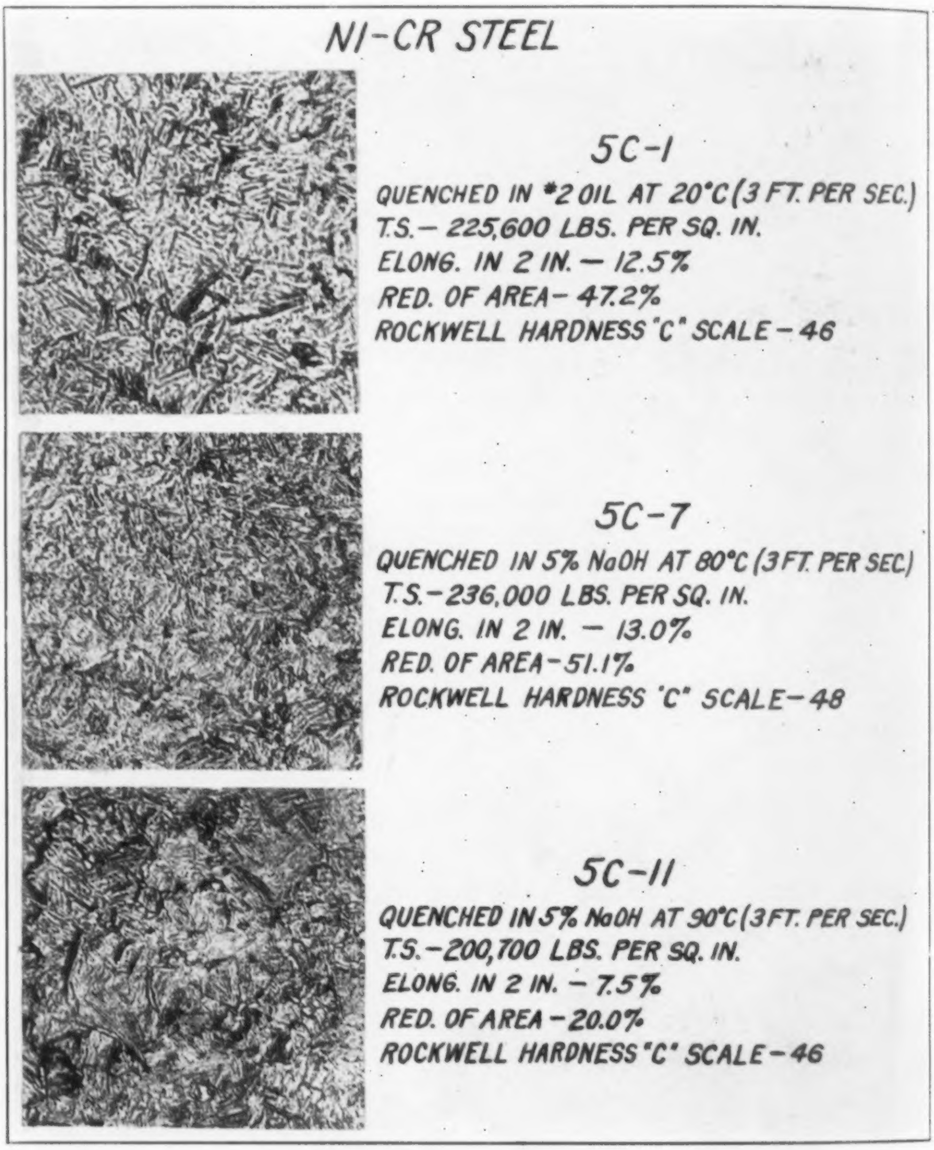

Fig. 84—Microstructures and Physical Properties of Some of the Tensile Specimens Tested; Summarized in Table IV. Microstructures which were Taken at Center of the Tensile Specimens Originally × 500, Reduced 40 Per Cent in Printing. Samples Etched in 2 Per Cent Nitric Acid in Alcohol.

to differences in the residual stresses left by the volume changes in hardening.

The three nickel-chromium steel samples shown in Fig. 84 showed structures consisting of partially tempered martensite; in the sample quenched in 5 per cent sodium hydroxide at 90 degrees Cent. dark needles were found suggesting the presence of troostite. These

Table XXV

Dimensional Changes and Cracking of the Gages Shown in Fig. 85 when Repeatedly Cooled in Different Liquids

Coolant (moving at 3 ft./sec.)	Dimension A, Fig. 85 in annealed steel, inch	Change in A, Fig. 85, upon quenching from 815° C (1) individual specimens, inch	Change in A, Fig. 85, upon quenching from 815° C (1) average inch	Further change in A, Fig. 85, upon tempering at 230° C (2) individual specimens, inch	Further change in A, Fig. 85, upon tempering at 230° C (2) average inch	Diameter change on quenching from 815°C individual specimens, inch	Diameter change on quenching from 815°C average inch	Rockwell Hardness ("C" Scale) after 1st quench	Rockwell Hardness ("C" Scale) after 1st quench and tempering at 230°C	Repeated Quenching from 815°C into specified coolant
No. 2 oil at 20° C	0.2482	+0.0037	+0.0029	+0.0004	+0.0004	+0.0037	+0.0032	51	50	
	0.2482	+0.0021		+0.0003		+0.0027		52	50	
No. 1 oil at 20°C	0.2484	−0.0001	+0.0005	+0.0005	+0.0006	+0.0025	+0.0026	52	49	
	0.2483	+0.0010		+0.0007		+0.0027		51	49	
Water at 70°C	0.2483	+0.0090	+0.0108	+0.0006	+0.0005	+0.0072	+0.0072	57	52	Cracked on 5th quench
	0.2485	+0.0125		+0.0004		+0.0072		57	51	Cracked on 5th quench
5% NaCl at 80°C	0.2485	+0.0134	+0.0144	+0.0008	+0.0008	+0.0056	+0.0056	57	51	Not cracked on 9th quench
	0.2482	+0.0153		+0.0007		+0.0056		55	52	Not cracked on 9th quench
5% NaOH at 80°C	0.2477	+0.0026	+0.0026	+0.0001	+0.0001	+0.0028	+0.0028	55	51	Cracked on 3rd quench
	0.2483	cracked						56	51	Cracked on 1st quench
5% NaOH at 90°C	0.2484	+0.0076	+0.0080	+0.0005	+0.0005	+0.0017	+0.0019	57	50	Not cracked on 9th quench
	0.2485	+0.0084		+0.0005		+0.0021		55	51	Not cracked on 9th quench

(1) 815 degrees Cent. or 1500 degrees Fahr.
(2) 230 degrees Cent. or 445 degrees Fahr.

samples showed low tensile strength and ductility in comparison with the samples quenched in oil at 20 degrees Cent. or 5 per cent sodium hydroxide at 80 degrees Cent.

5. Dimensional Changes in the Hot Aqueous Solutions

Gages of the form and dimensions shown in Fig. 85 were quenched in each of the two oils and in some of the hot aqueous solu-

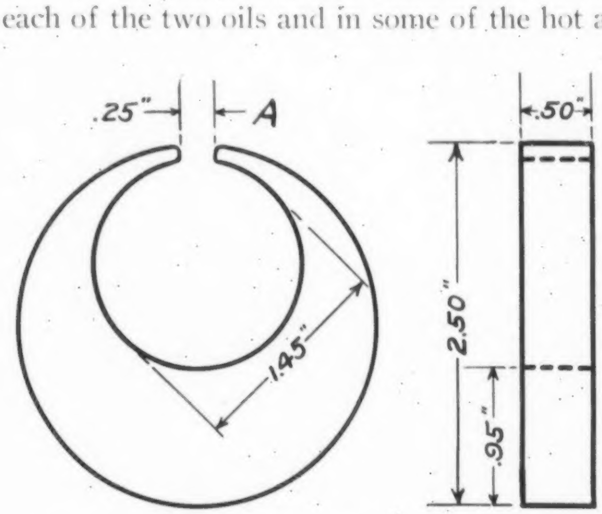

Fig. 85—Form and Dimensions of the Gage Used in the Repeated Quenching Experiments.

tions and the resulting changes in diameter and in the width of the slot A are summarized in Table XXV.

The gages used were similar to those employed in the inspection of class 5 tool steels by the U. S. Navy Department[32] except that they were exactly half size in all dimensions. Johanssen gage blocks were used in measuring the width of the slot A while the diameters were measured at points ¼ inch to ½ inch from each side of the slot A. The gages were all brought to a constant temperature of 20 degrees Cent. before measurements were made.

For the first quench the gages were placed in a furnace at 815 degrees Cent. (1500 degrees Fahr.) held 45 minutes and immersed in the chosen liquid. After the desired measurements had been made, the gages were tempered for one hour at 230 degrees Cent. (445 degrees Fahr.) and again measured. Subsequently, the gages were repeatedly quenched into the solutions first used but in these cases they were held in the furnace only 15 minutes before quenching.

[32]0.80 to 1.05 per cent Carbon, 1.25 to 2.00 per cent Manganese; Navy Department Specifications for Tool Steel, No. 47S5c, July 1, 1921.

The steel originally selected for the tests was an "oil hardening" steel containing about 0.9 per cent carbon, 1.2 per cent manganese and about 0.5 per cent each of chromium and tungsten but due to an error which was not discovered until after the experiments had been completed the gages were made from a steel containing 0.45 per cent carbon and 1 per cent chromium. However, this latter steel served the purpose of the experiments since the coolants of greatest interest were those having cooling rates between the oils and ordinary tap water at atmospheric temperatures and an "oil hardening" steel was not essential.

The object of the tests described was to detect in a practical and empirical manner conditions which might be characterized as dangerous in the application of the different coolants. The form of the specimen illustrated in Fig. 85, with its thin and heavy sections, precludes uniform cooling and the stresses set up by the volume changes in hardening cannot readily be calculated on account of the complexity of the conditions encountered in different parts of the gage, but should certainly be high. Therefore, this specimen offers a means of detecting strong tendencies of the different coolants to promote distortion and cracking, irrespective of the causes of these effects.

The changes in diameter may be taken to indicate roughly the volume changes in hardening while those in the width of the slot A, Fig. 85, should reflect qualitatively the magnitude of the internal stresses set up by these volume changes since the ends forming the slot are free to move.

As is shown in Table XXV the changes in the width of the slot A, Fig. 85, were larger, per unit of measured length, than those in the diameter of the gages but the two sets of changes showed simultaneous increases or decreases when comparing the different coolants. With one exception, the changes were larger in the hot aqueous solutions than in the oils (Table XXV). This one exception was the sodium hydroxide at 80 degrees Cent. in which the dimensional changes were about equal to those in the No. 2 oil and smaller than the changes in any of the other liquids except the No. 1 oil. The Rockwell hardness produced in metal adjacent to the slot was somewhat higher when the gages were quenched in the sodium hydroxide at 80 degrees Cent. (55, "C" scale) than when quenched in either of the oils (51 or 52 for both oils).

In all cases the changes produced by tempering for one hour at 230 degrees Cent. (445 degrees Fahr.) were small, and this may be

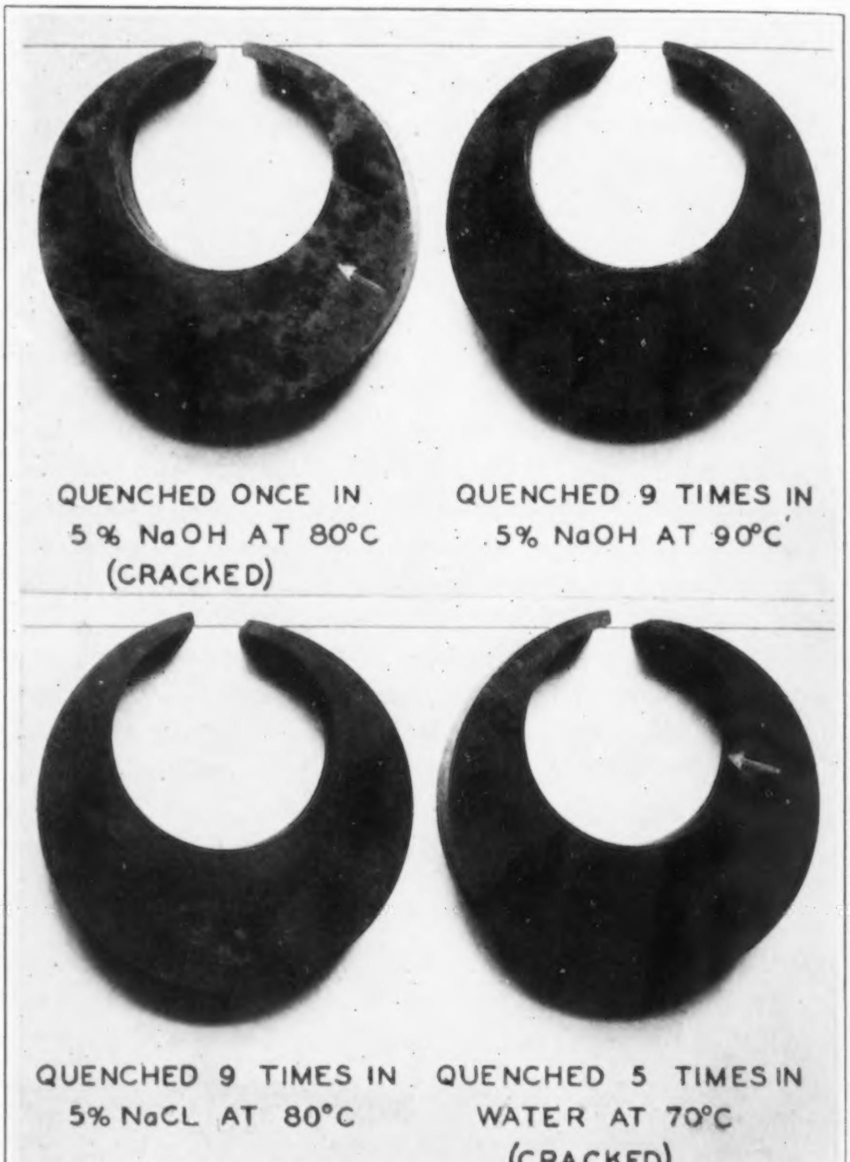

Fig. 86—Some of the Gages After Repeated Quenching in Some of the Hot Aqueous Solutions. Arrows Point to Cracks.

taken to indicate that the widening of the slot in quenching effectively relieved a large part of the internal stresses produced by the volume changes in hardening.

The results obtained in these experiments justify the view that some of the hot aqueous solutions can be useful in bridging the gap between the cooling rates obtained with water and oils at ordinary

temperatures, but some of their characteristics must be recognized as sources of danger or disadvantage. The maintenance of rapid cooling at low temperatures may be undesirable in the hardening of some steels but this also applies to drastic coolants such as the cold brines and cold sodium hydroxide solutions now used industrially. Difficulties from this source can be minimized in some cases, at least, by removing the steel before it reaches coolant temperatures (interrupted quenching) and under suitably controlled conditions any benefits derived need not be at the expense of high hardness. Another source of danger in the hot aqueous solutions is lack of uniformity, promoted by the formation of relatively large amounts of steam but this becomes more marked as the bath temperature approaches the boiling point of water and can probably be counteracted through adequate circulation and adjustment of coolant composition and temperature.

Such sources of danger are well recognized but the hot aqueous solutions studied are not necessarily "poisonous" to steels as is illustrated by the results of the repeated quenching summarized in Table XXV.

Under the adverse conditions imposed by repeated introduction of the hardened steels into a furnace at high temperatures, without intermediate annealing, two of the gages cracked in the first and third quenchings in the 5 per cent sodium hydroxide at 80 degrees Cent. but five treatments were required for cracking in water at 70 degrees Cent. and the gages did not crack when quenched nine times in either 5 per cent sodium chloride at 80 degrees Cent. or 5 per cent sodium hydroxide at 90 degrees Cent.

The appearance of some of the repeatedly quenched gages is shown in Fig. 86, and it will be observed that considerable distortion has taken place in the ends forming the slot in those gages which were quenched nine times without cracking. The cracks in the gages quenched in 5 per cent sodium hydroxide at 80 degrees Cent. were in the heavy section (see arrows, Fig. 86), whereas those in the gages quenched in water at 70 degrees Cent. were circumferential at the hole in the specimen (see arrows, Fig. 86).

Not enough tests were made to determine the best of the liquids tested for different purposes nor the order of uniformity which may be expected under conditions of practical application but the described results seem to justify the conclusion that the hot aqueous solutions will, upon further study of concentrations and cir-

culation, offer a useful set of coolants to bridge the gap between water and oils at atmospheric temperatures, at least for the hardening of *small* steel parts.

Chapter VI

CRITICAL COOLING RATES AND DEPTH HARDENING PROPERTIES OF STEELS

1. Quenching Diagrams

It was pointed out that the properties produced in steels by given coolants are dependent upon the composition of the steel and upon variables of manufacture. Variations from both sources affect the cooling rates required for complete hardening or what is frequently called complete martensitization[33].

While metallurgists do not all agree upon the sequence of the formation of the different microstructures in steels cooled at different rates, they quite generally subscribe to the idea, which is associated with the pioneer investigations of French metallurgists, that there is a critical cooling rate which must be reached to secure martensite free from troostite[34] and hence full hardening.

The conception now generally accepted is that with progressive increase in the cooling rates the Ar_1 transformation is at first lowered slightly and then splits so that it takes place partly at high temperatures and partly at low temperatures in the neighborhood of 300 degrees Cent. (570 degrees Fahr.) With further increase in the cooling rates there is a discontinuity in the lowering of the transformations in that the heat effect at the high temperature disappears and only the low temperature point is observed.

The upper part of the split transformation is considered to represent the formation of troostite from austenite and has been designated Ar'; the low temperature transformation represents the formation of martensite and has been designated Ar''. The cooling rate at which Ar' disappears is the critical cooling rate, referred to above, and marks the disappearance of primary troostite and the retention of a martensitic-austenitic structure.

[33]These terms refer to martensite without primary troostite; austenite may be, and usually is, also present under the customary quenching conditions.

[34]A summary of the different views of the sequence of the formation of the different microstructures in quenched steels is given in a recent paper by J. M. Robertson, "The Microstructure of Rapidly Cooled Steel," *Journal*, Iron and Steel Institute, Vol. 119, 1929, p. 391.

Table XXVI

Carbon Steels Used in the Determination of Critical Cooling Rates

Steel Number	Chemical Composition per cent C	Mn	P	S	Si	McQuaid-Ehn test, grain size no.	Critical cooling rate deg. C per sec.	Quenching temperature used in experiments deg. C
				1st Group				
C31	.25	.51	.011	.036	.01	3	600 (estimated)	920
C33	.43	.60	.018	.023	.11	2	220	875
C29	.75	.29	.011	.023	.11	5	175	830
A316	.89	.33	.014	.035	.18	.	160	875
C27A	.96	.21	.019	.018	.21	5	160	875
C28	1.27	.21	.013	.021	.17	7	255	810
				2nd Group				
3H	.34	.58	.016	.041	...	8.5	380	870
3C	.47	.72	.017	.025	...	7	265 (290)[1]	840
S	.62	.37	....	....	.10	3	290 (135)[1]	820
P	.81	.30	....	....	.18	4	215 (175)[1]	800
M	1.10	.28	....	....	.20	3	195 (145)[1]	790
L	1.23	.28	....	....	.26	5	130	760

[1] These samples of the 2nd group of steels were hardened from the "As received" condition; many contained cementite network and were coarse as viewed under the microscope. The remaining samples of the 2nd group of steels were sorbitized, by oil quenching from 1700 degrees Fahr. and tempering at 1100 degrees Fahr. for two hours before heating for hardening.

These changes in the temperatures at which the transformations take place are important from the viewpoint of practical heat treatment since they represent a complete range of structures and properties from the relatively soft condition to that of high hardness. When the changes in the transformation temperatures with cooling rates are correlated with the structures and properties of steels a picture is obtained of their heat treatment characteristics and useful comparisons can then be made of different steels.

The early investigations upon which the foregoing conceptions are based were carried out largely with alloy steels having low critical cooling rates. Therefore, studies were made of the corresponding changes in carbon steels which require rapid cooling for hardening. The steels tested originally had the chemical compositions recorded in Table XXVI (1st Group) and the results of the quenching experiments are summarized in the "quenching diagrams" reproduced in Figs. 87 to 93 inclusive. These show the relations between the cooling rates, taken at 720 degrees Cent. (1330 degrees Fahr.), the temperatures of occurrence of the transformations, the structures and the hardness.

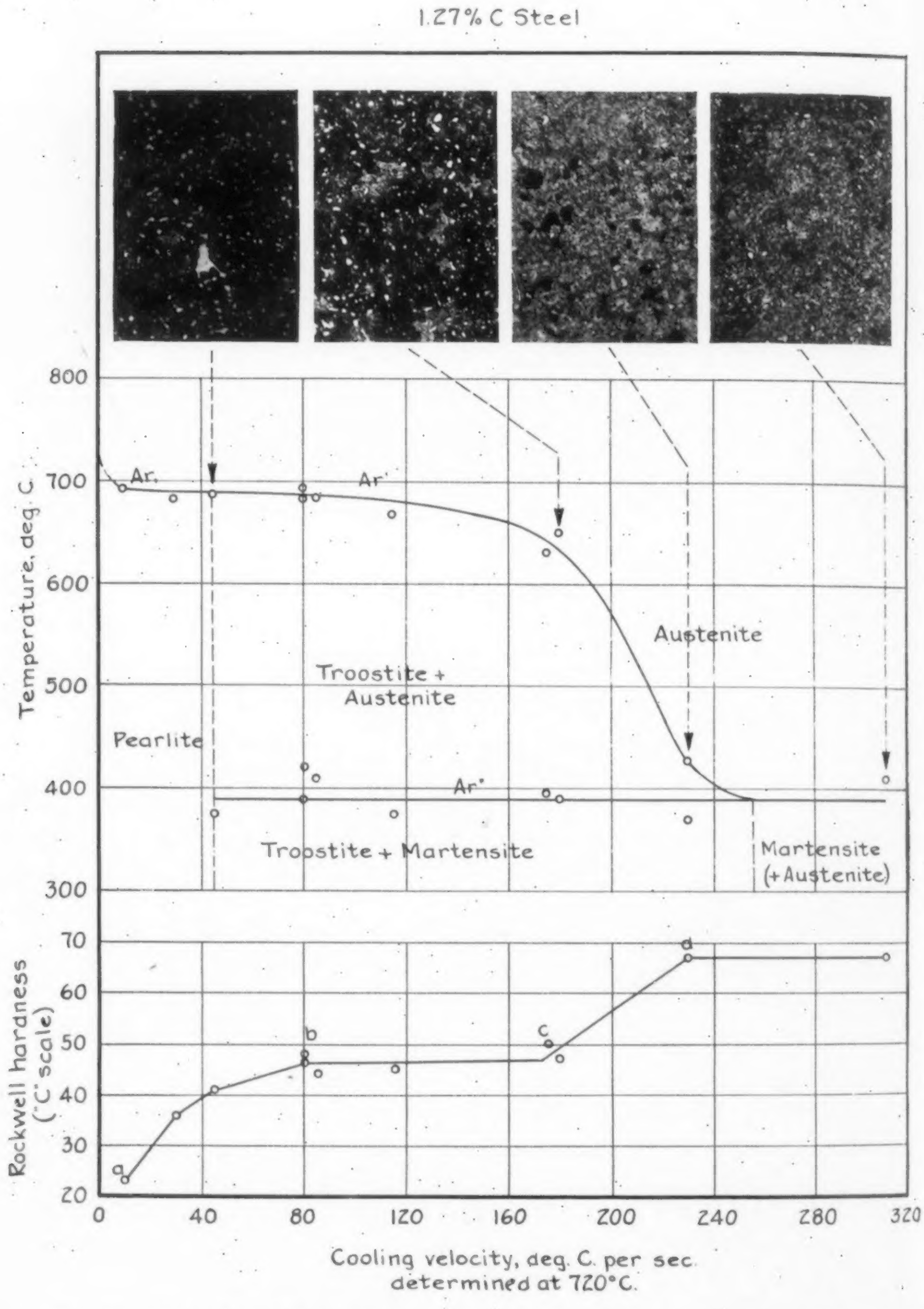

Fig. 87—"Quenching Diagram" for 1.27 Per Cent Carbon Steel Quenched from 810 Degrees Cent. Microstructures Given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol.

(A). To Determine Whether the Dark Areas Shown in the Two Photomicrographs at the Extreme Right were Troostite or Graphite Examination of Unetched Sections was also Made.

(B). The Retention of Austenite is Indicated in this and Subsequent Diagrams (Figs. 87 to 92, inclusive) only for Rates Higher than the Critical. Some may be Present in Steels Cooled More Slowly.

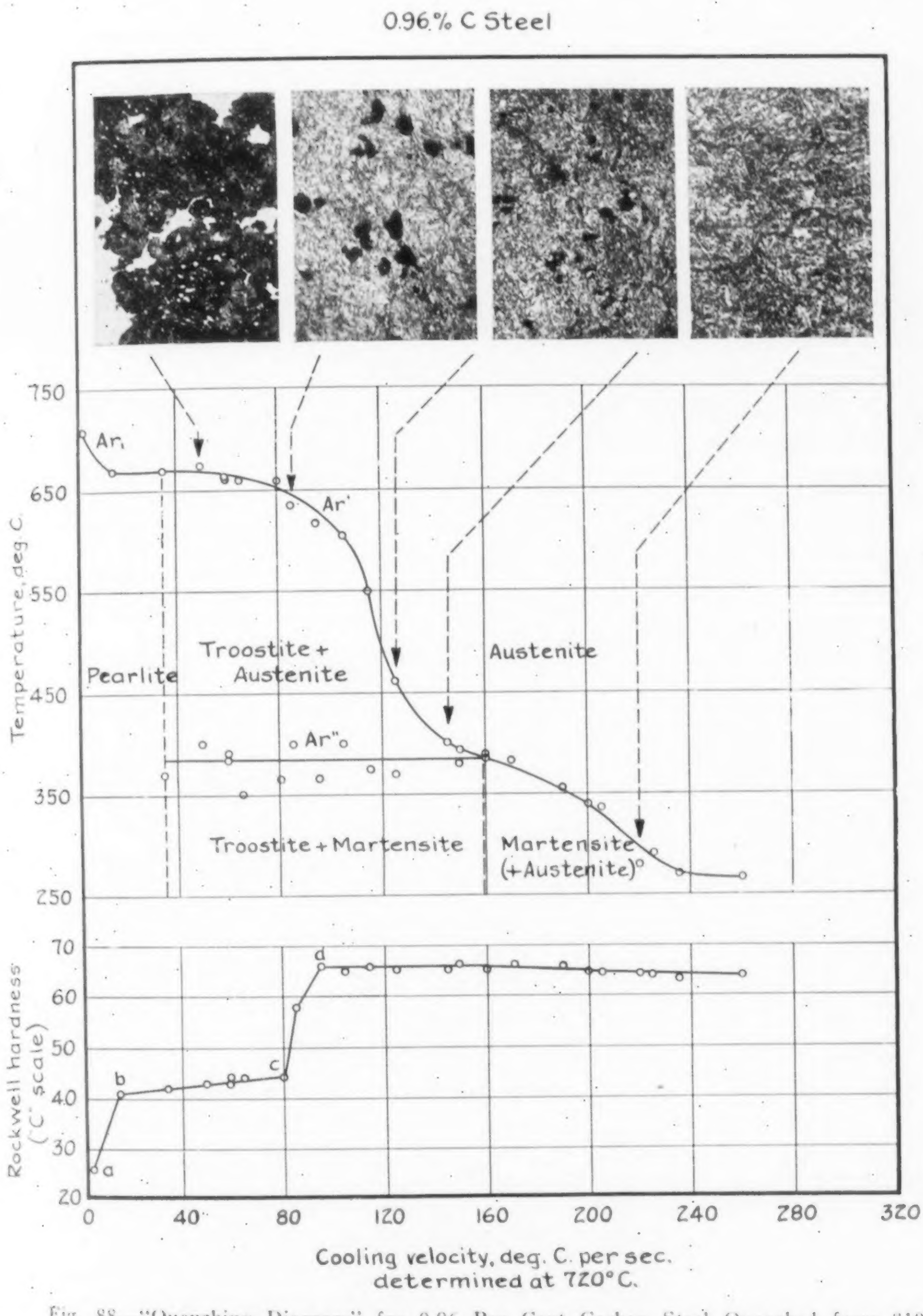

Fig. 88—"Quenching Diagram" for 0.96 Per Cent Carbon Steel Quenched from 810 Degrees Cent. Microstructures Given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 87.

The general character of these quenching diagrams is the same for all of the steels studied and it will be noted that as the cooling rates were progressively increased the Ar_1 transformation was at

first lowered slightly and then split. The structure changed from pearlite or sorbite to troostite and austenite and the hardness increased appreciably. With further increase in the cooling speeds the heat effect of the upper part of the transformation, Ar′, decreased in intensity while that of the low temperature transformation, Ar″, increased in intensity but the temperature of its occurrence did not change appreciably. With sufficiently rapid cooling only the low temperature transformation was observed and primary troostite was no longer evident. The structure then consisted of martensite (and austenite) and full hardness was obtained.

The quenching diagrams in Figs. 87 to 93 inclusive differ in one detail from those previously secured for air hardening alloy steels in that the temperature of occurrence of Ar′ is shown to approach that of the martensite transformation, Ar″, instead of disappearing at relatively high temperatures at the critical cooling rate. At the time the experiments were made this seemed to be the proper method of summarizing the results but the evidence of the marked lowering of Ar′ before its disappearance at the critical cooling rate is not conclusive since the thermal effects were all small and difficult to detect even when replotting the cooling curves by the inverse rate method (Fig. 94). It was also not practicable with the chosen methods of test to locate accurately the cooling rates at which Ar_1 first split but both these matters were considered to be of secondary importance in the investigation and need not be discussed in further detail.

In the preceding discussion the customary terminology has been employed as a matter of convenience but this does not imply acceptance of the conception of a true splitting of Ar_1, at the designated positions of Ar′ and Ar″. These heat effects may represent the maximum speeds of reactions in a transformation range which has widened materially. However, the accepted terminology is a convenient means of summarizing the data for the comparisons of the different steels.

The importance of the changes in the occurrence of the transformations is shown by the structures and hardness test results included in the quenching diagrams of Figs. 87 to 93 inclusive. In the steels containing 0.75 per cent or more of carbon the hardness increased appreciably with the cooling rate until a fairly large amount of troostite was formed (region ab). It then remained practically constant over an appreciable range of cooling rates (bc) until the cooling was sufficiently rapid to make martensite the predominating

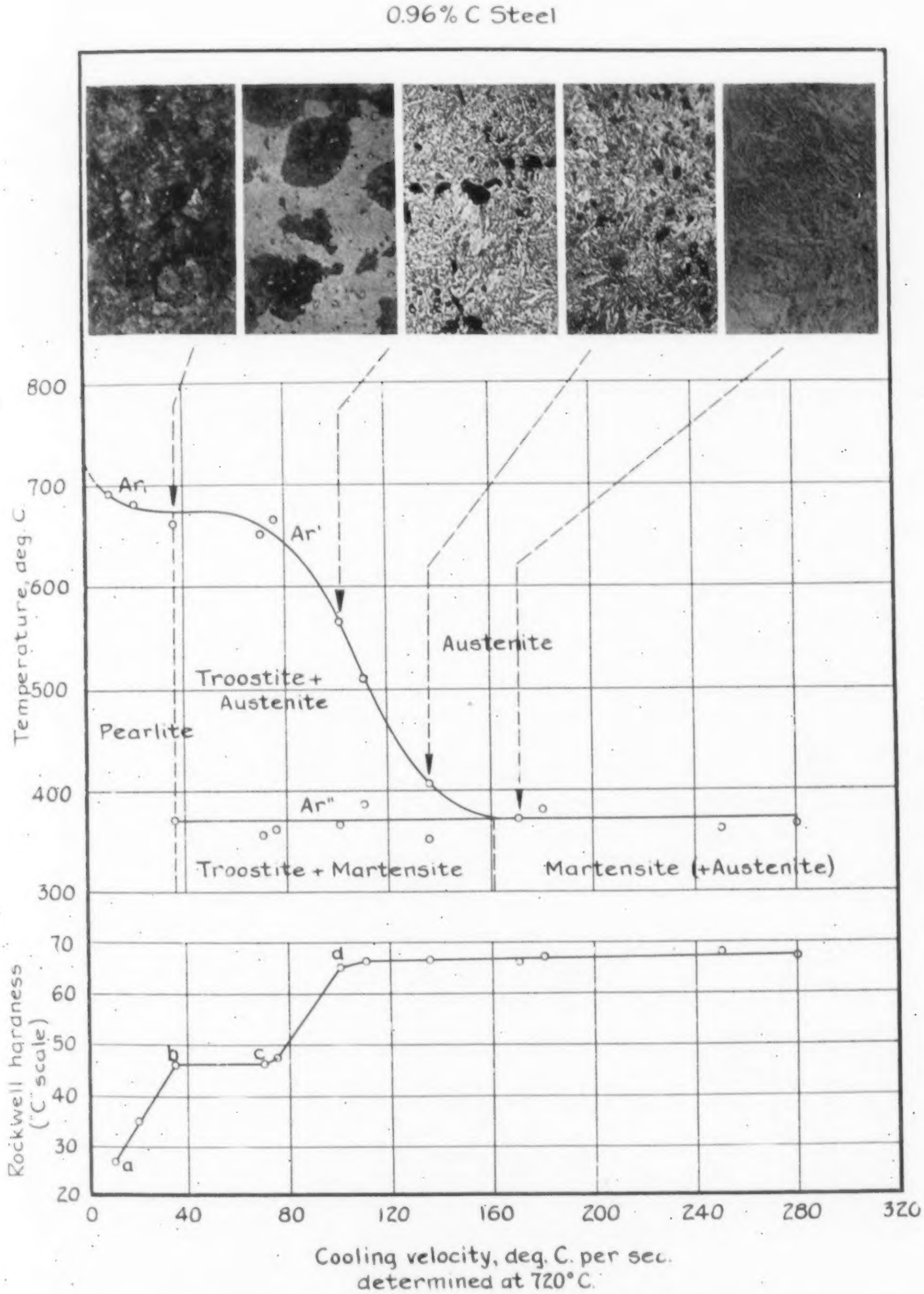

Fig. 89—"Quenching Diagram" for 0.96 Per Cent Carbon Steel Quenched from 875 Degrees Cent. Microstructures Given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 87.

constituent when it again increased (region cd). Above the critical cooling rate and within the limits investigated, the hardness remained very nearly constant. The hardness curves, unlike those for

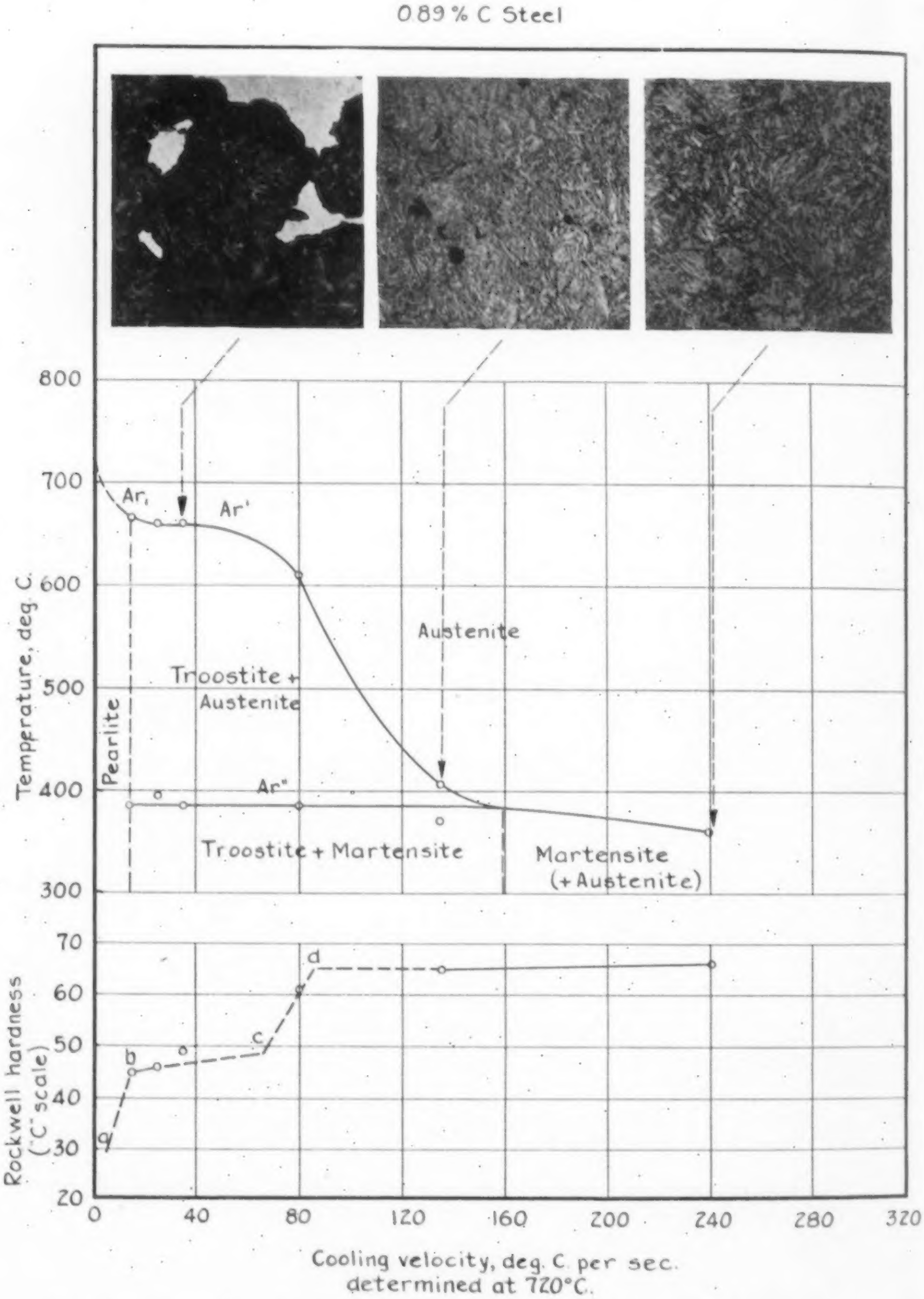

Fig. 90—"Quenching Diagram" for 0.89 Per Cent Carbon Steel Quenched from 875 Degrees Cent. This Diagram, Unlike Those in Figs. 87 to 89 and 91 and 92, was Obtained by Varying the Sample Diameter from ⅛ to 2 Inches, but with a Constant Ratio of Length to Diameter of 3. Its Sole Purpose is to Check Results Obtained by Using Different Quenching Media. Microstructures Given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 87.

the thermal transformations, have been plotted with sharp breaks through points of observations; somewhat more gradual changes probably would have been shown with the acquisition of intermediate points on these curves.

It is important to note that in the high carbon steels, containing from 0.75 to 1.25 per cent carbon, practically identical hardness values were obtained with appreciable proportions of troöstite and a completely martensitic product (not containing too much austenite). Experience has shown that there may be material differences in the performance of fully hardened (martensitic) steels and those containing appreciable proportions of troöstite mixed with the martensite. In applications such as automotive gears requiring high resistance to deformation, great toughness and resistance to fatigue and abrasion, the troostitic steels will often have only a fraction of the useful life of the fully martensitic product[35] even though comparable hardness values are obtained with the customary test methods. It would, therefore, seem to be necessary to use caution in applying indentation hardness tests to hardened steels for the purpose of insuring adequate hardening since such tests will not necessarily differentiate between satisfactory and unsatisfactory structures. "Soft spots" from primary troostite can be detected more readily and with greater certainty by the file in skillful hands. While a rough test and subject to objectionable features a file test is often quite valuable for inspection to guarantee performance which is dependent upon the correct hardening of steels.

2. Critical Cooling Rates of Carbon Steels

If the differences in manganese and silicon contents and variations in methods of manufacture of the first group of steels, Table XXVI, are disregarded the quenching diagrams of Figs. 87 to 93 can be used to determine, at least in a general way, the effects of carbon content upon the reactions of plain carbon steels to different rates of cooling. A graphical summary of important features of the quenching diagrams is given in Fig. 95.

A feature of direct practical interest is the critical cooling rate. The steels with approximately the eutectoid carbon contents (in the neighborhood of 0.85 per cent carbon) had the lowest critical cooling rates. Increase or decrease in the carbon content resulted in an in-

[35]Private communication.

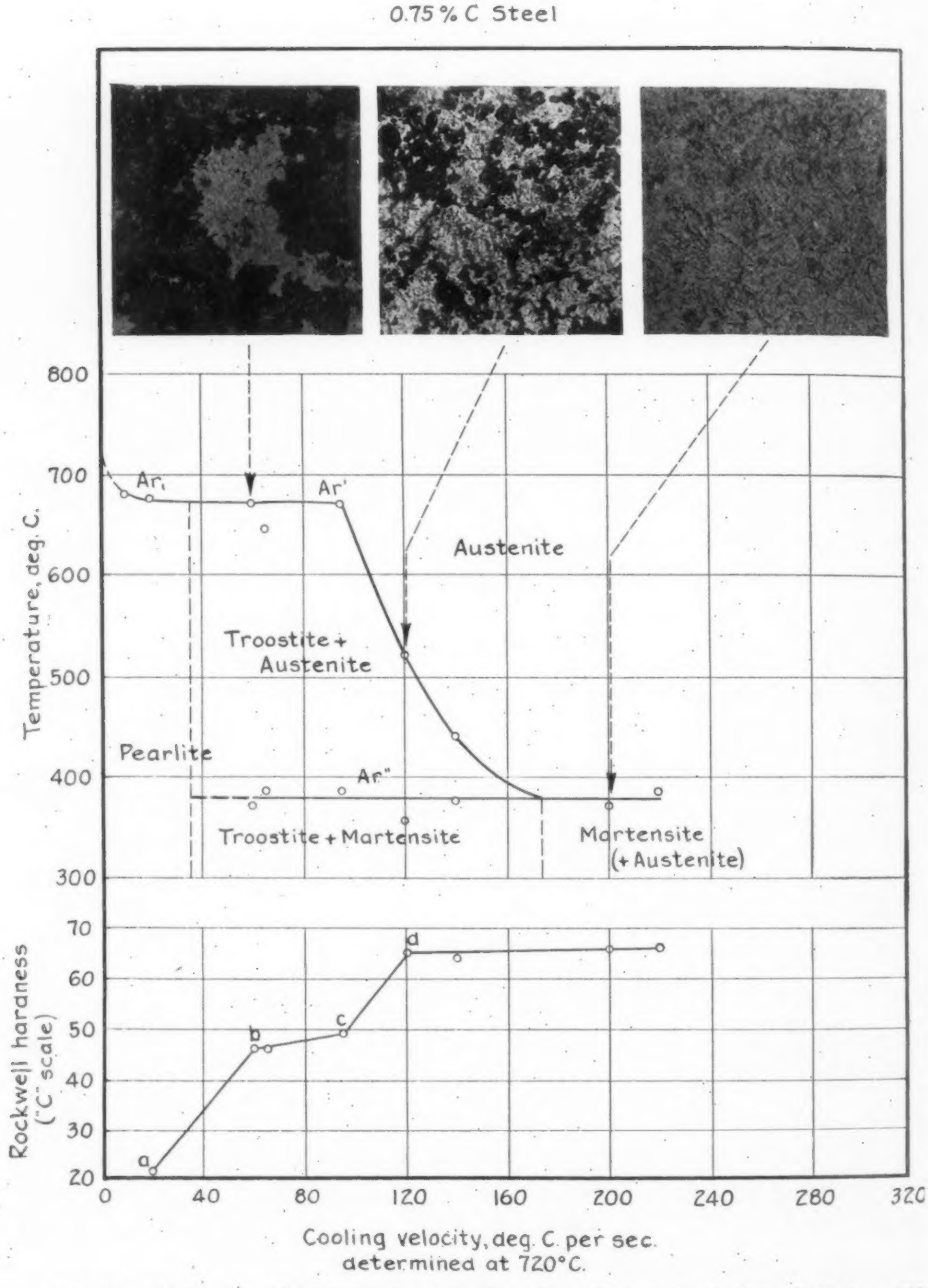

Fig. 91—"Quenching Diagram" for 0.75 Per Cent Carbon Steel Quenched from 830 Degrees Cent. Microstructures Given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 87.

crease in the critical rates. These differences mean that less rapid cooling is required for the full hardening of carbon steels with about 0.8 to 0.9 per cent carbon than for steels of either higher or lower

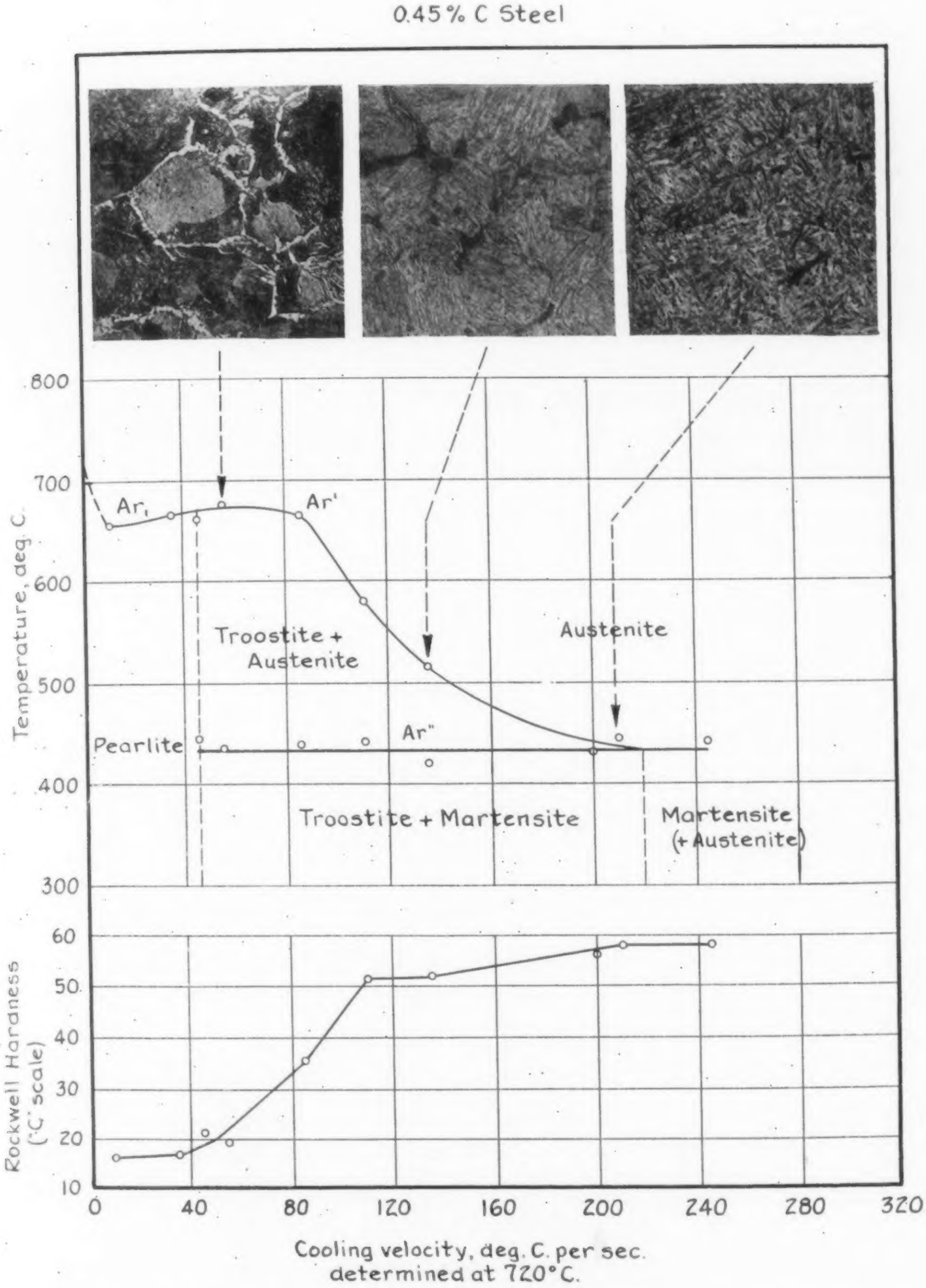

Fig. 92—"Quenching Diagram" for 0.45 Per Cent Carbon Steel Quenched from 875 Degrees Cent. Microstructures Given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 87.

carbon contents and similarly that steels with about the eutectoid proportions of carbon will, if all other variables remain constant, harden

more deeply in water or other coolants than will steels with much higher or much lower carbon contents when similarly quenched.

However, the hardness of the martensite is dependent upon the carbon content and only in the high carbon steels with about 0.7 per cent or more of carbon will a Rockwell "C" scale hardness of 65 to 68 be obtainable. Within the range 0.7 to 1.25 per cent carbon the hardness obtained with the critical quenching speed was substantially constant but as the carbon content of the steel was lowered the hardness decreased (Fig. 95).

The relation between carbon content and the temperatures of occurrence of Ar″ is likewise shown in Fig. 95. The temperature at which martensite is formed during quenching was lowered with increase in carbon to about 0.60 to 0.70 per cent; it remained at about 375 degrees Cent. (705 degrees Fahr.) for steels containing between about 0.70 to 1.25 per cent carbon. The same type of curve was obtained for the relation between carbon content and the cooling rate at which Ar″ was first observed.

The results discussed in preceding paragraphs were obtained with two exceptions (Figs. 89 and 90) by quenching from a temperature about 75 degrees Cent. above Ac_3 for hypoeutectoid steels and Ac_1 for hypereutectoid steels. These temperatures are generally higher than the quenching temperatures used commercially for small sections especially in the case of the high carbon steels but the trends should not be altered by lower quenching temperatures. Experiments were also carried out with the 0.95 per cent carbon steel quenched from about 140 degrees Cent. above Ac_1 and as is shown by comparison of Figs. 88 and 89 the only marked variations in the character of the quenching diagrams was in the progressive lowering of Ar″ at cooling speeds greater than the critical. With the higher initial temperature (875 degrees Cent.) this sloped sharply downward so that martensite was formed at about 260 degrees Cent., (500 degrees Fahr.) instead of 375 degrees Cent., (705 degrees Fahr.) when cooling at 250 degrees Cent. (480 degrees Fahr.) per second. However, there was no observable change in the numerical value of the critical cooling velocity with this increase in initial temperature.

3. McQuaid-Ehn Grain Size Versus Critical Cooling Rates

In the preceding discussion it was assumed that the steels tested differed only in carbon content. Examination of Table XXVI shows

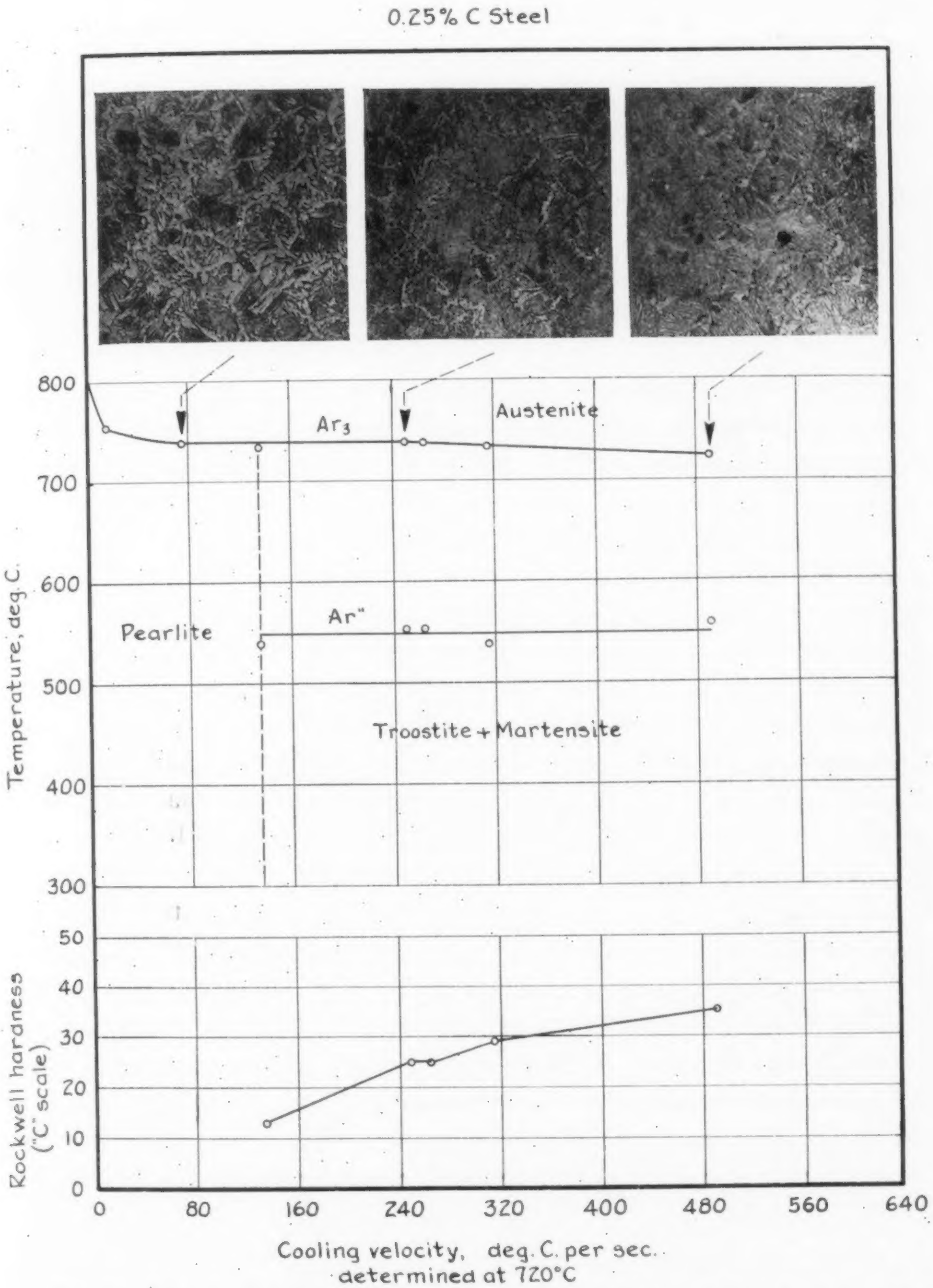

Fig. 93—Part of the "Quenching Diagram" for 0.25 Per Cent Carbon Steel Quenched from 920 Degrees Cent. Microstructures Given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Note that this Diagram is Incomplete and that the Upper Line is Ar_3. A Heat Effect from Ar_1 or Ar' Could Not be Detected with the Methods Used.

they differed appreciably in some cases also in manganese content and did not all have comparable grain size ratings in the McQuaid-Ehn

that carburizing test.[36] It is known that manganese tends to lower the critical cooling rates (promote deep hardening) and it is believed that coarse-grained steels will harden more deeply than corresponding fine-grained steels, i.e. have lower critical cooling rates.

The tests described were not sufficient to permit a study of the effects of grain size upon the critical cooling rates but more recently additional data were secured on a second group of carbon steels and have been combined with the original results in Table XXVI and Fig. 96. In the second set of tests the critical cooling rates were obtained by quenching cylinders of different diameters in water, determining microscopically the maximum size which showed no primary troostite at the geometrical center of the cylinder and then computing the cooling rates by means of the equations given in Chapter II.

The most striking feature of Fig. 96 is the wide scatter of points representing the critical cooling rates of the different carbon steels. However, when due recognition is given to the variations in manganese content it would appear that the coarse-grained steels, represented by the low grain size members, tended to show the lowest critical cooling rates. But even so the results are not entirely consistent and suggest that the critical cooling rates of carbon steels are dependent upon variables which are not reflected in the simple interpretations given to the results of the McQuaid-Ehn carburizing test. On the other hand, the scatter of points in Fig. 96, for the second set of tests, may be due largely to the hand quenching which may not have been carried out under sufficiently close control or to the presence of small proportions of impurities not determined in the tests.

While it is not practicable at this time to fix values for the critical cooling rates of carbon steels of different grain sizes and manganese contents there are some definite trends shown in Fig. 96 which are of practical importance. Low manganese, fine-grained steels have

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[36]For discussions of the McQuaid-Ehn carburizing test refer to: H. W. McQuaid and E. W. Ehn: "Effect of Quality of Steel on Case Carburizing Results," *Transactions*, A. I. M. E., Vol. 57, 1922, p. 341; E. W. Ehn, "Influence of Dissolved Oxides on Carburizing and Hardening Qualities of Steel." *Journal*, Iron and Steel Institute, Vol. 105, 1922, p. 157; E. W. Ehn, "Irregularities in Case Hardened Work Caused by Improperly Made Steel," TRANSACTIONS, American Society for Steel Treating, Vol. 2, 1922, p. 1177; S. Epstein and H. S. Rawdon, "Progress in Study of Normal and Abnormal Steel," TRANSACTIONS, American Society for Steel Treating, Vol. 12, 1927, p. 337.

The practice employed in carburizing and in rating grain size varies somewhat in different laboratories. A representative practice and the one used as a basis for the data in this paper is approximately as follows. Carburize for 10-13 hours at 1650-1700 degrees Fahr.; at 100 magnification No. 1 grain size contains up to 1½ grains per sq. inch; No. 2 contains 1½ to 3 grains per sq. inch; No. 3, 3 to 6; No. 4, 6 to 12; No. 5, 12 to 24; No. 6, 24 to 48; No. 7, 48 to 96; No. 8, 96 to 192; No. 9, 192 or more.

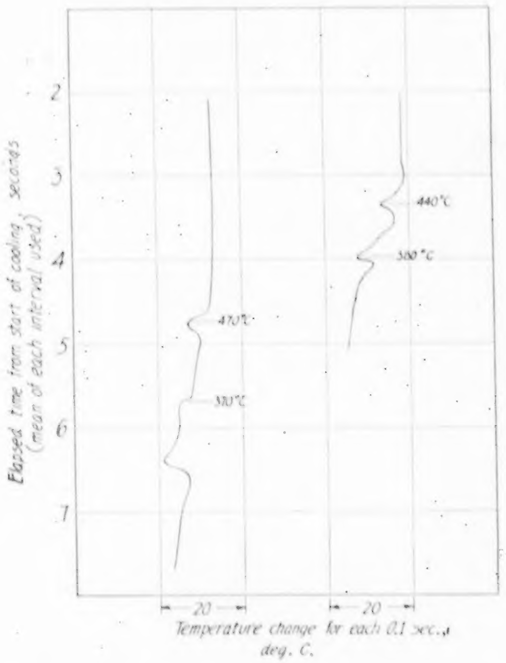

Fig. 94—Partially Re-plotted Cooling Curves Showing the Temperature Drop for Equal Time Intervals. This Method of Re-plotting was Used when the Heat Effects of Ar′ or Ar″ were Very Small. The Two Curves Reproduced Show a "Lowered" Ar′ in the Sensitive Zone on the Quenching Diagrams Just Below the Critical Cooling Rate. The Curve at the Left was Obtained at the Center of a ½-Inch Diameter Cylinder of 0.95 Per Cent Carbon Steel Quenched from 875 Degrees Cent. Into Still Water at 40 Degrees Cent.; that at the Right is for a Cylinder 7/16-Inch Diameter of 0.75 Per Cent Carbon Steel Quenched from 830 Degrees Cent. Into Still Water at 30 Degrees Cent.

relatively high critical cooling rates; they are shallow hardening and require the most rapid coolants for complete martensitization. The coarse-grained steels, and especially those with manganese on the high side of the usual commercial ranges have the lowest critical cooling rates, therefore are deep hardening and require less rapid cooling. Variations of manganese and grain size, within limits encountered in commercial practice, may alter the critical cooling rates and hence the depth hardening properties more markedly than appreciable variations in carbon content. In fact Fig. 96 suggests that carbon content is the least important of the variables considered at least within the range 0.7 to 1.25 per cent carbon.

The range of variations in critical cooling rates between the low manganese, fine-grained steels and the higher manganese coarse-grained steels as well as the critical cooling rates of steels with about

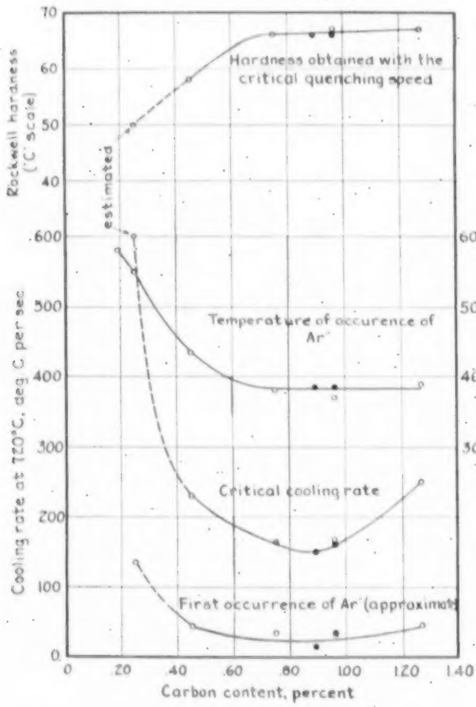

Fig. 95—Approximate Effects of Carbon Content on the Critical Cooling Rates and Some Other Features of the Quenching Diagrams for Carbon Steels when Quenched Under Definite Conditions. In All Except Two Cases Represented by Solid Black Circles in which the Samples were Cooled from 875 Degrees Cent., Quenching was Carried Out from About 75 Degrees Cent. Above Ac_3 for Hypoeutectoid Steels and Ac_1 for Hypereutectoid Steels.

0.3 per cent manganese and No. 5 grain size in the McQuaid-Ehn test are shown approximately by the 3 curves in the upper part of Fig. 96. These are, of course, estimations but serve to emphasize the trends of the effects described. For convenience the upper and lower boundaries of the range of critical cooling rates have been expressed in the lower half of Fig. 96 in terms of the cylinder sizes which will harden throughout and the numerical values are consistent with those recently reported by Shepherd.[37]

In the light of these results, it is, perhaps, not difficult to understand why users prefer one or another source of supply of tool steels. While comparable surface hardness can be secured over a wide range of carbon contents and grain sizes, commercial carbon steels vary appreciably in their depth hardening properties and such variations

[37] B. F. Shepherd: "Inherent Hardenability Characteristics of Tool Steel," TRANSACTIONS, American Society for Steel Treating, Vol. 17, Jan., 1930, p. 90.

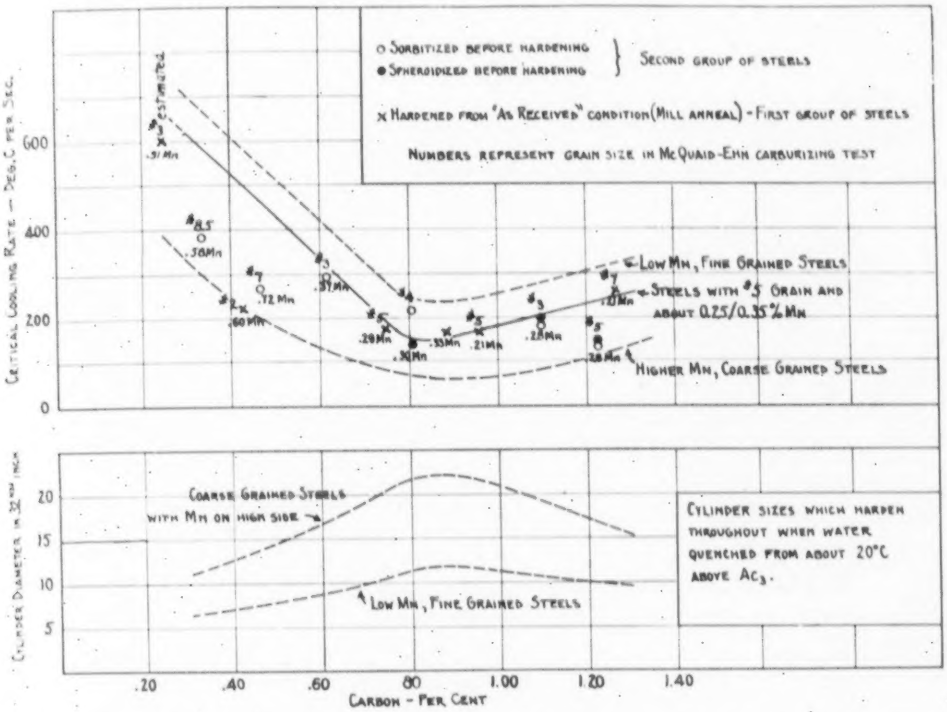

Fig. 96—Critical Cooling Rates and Depth Hardening Properties of Plain Carbon Steels as Affected by Carbon and Manganese Contents and Grain Size.

sometimes represent the difference between success and failure in service. Specifications requiring close carbon control but which disregard the heat treatment characteristics will often be inadequate for refined work since the qualities which appear desirable for one application may be undesirable for others. Deep hardening steels are desired in the manufacture of some metal cutting tools such as twist drills to permit retention of a hard point on repeated resharpening while shallow hardening steels are favored for small punches, where the gain in toughness from a "soft" core is important.

The experiments described can hardly be applied directly to the inspection of steels but simplified tests designed to develop the depth hardening properties of tool steels have already been devised.[38] They should, of course, not be applied unnecessarily but can be helpful where close control is essential.

4. Grain Size Versus Properties of Hardened Steels

The matter of grain size variations in relation to the properties

[38]Refer to footnote 37.

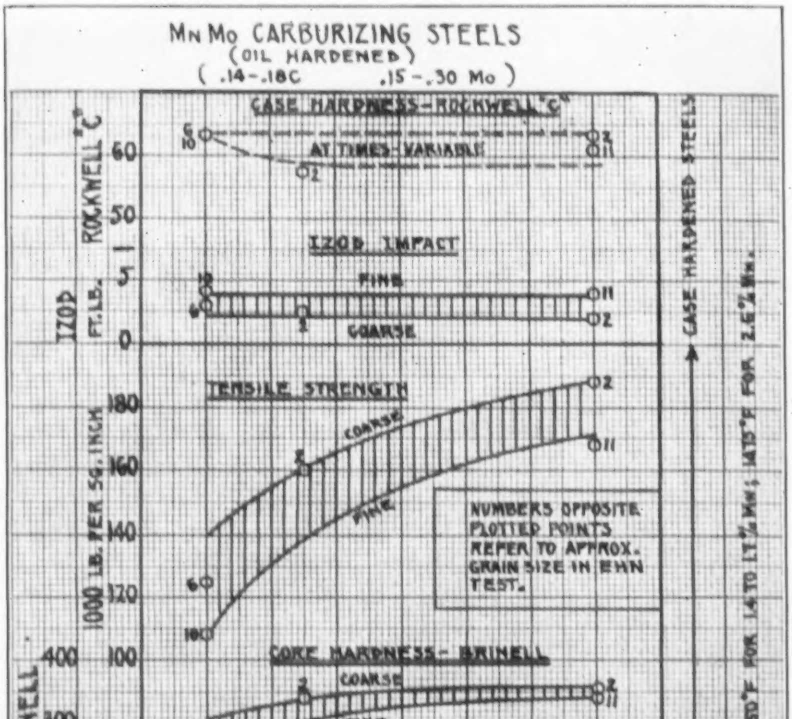

Fig. 97—Effect of Grain Size and Manganese Content on the Properties of Quenched Manganese Alloy Carburizing Steels.

of steels is one of general interest and not restricted in its practical importance to plain carbon tool steels. Fig. 97 representing the properties of quenched manganese alloy steels, of carburizing grades, shows that the coarse-grained steels had the higher strengths but were inclined to be brittle. Variations in notch test values between the coarse-grained steels and the fine-grained steels were quite large but even the tensile properties were affected to as great a degree by grain size variations as by appreciable variations in the alloy content.

The grain size ratings in the McQuaid-Ehn carburizing test are a convenient basis of reference but the causes of the variations in properties which they represent are not always known or understood. Nevertheless it becomes apparent that factors other than the proportions of elements now ordinarily determined by the steel analyst must be considered in the quenching of steels and that these factors may exert a more pronounced influence upon the results obtained with hardened steels than appreciable variations in carbon or alloy contents.

Chapter VII

GENERAL COMPARISONS OF DIFFERENT COOLANTS

1. "Hardening Power"

The matter of securing a single numerical value to represent the "hardening power," or the "quenching power" of liquids has received the attention of different investigators and is of some interest in the comparison of coolants. If, as has generally been the case, "quenching power" is defined as the ability to absorb heat rapidly this term is roughly the equivalent of "hardening power" since the rates of temperature drop control the lowering of the transformations and hence the hardening produced in steels.

Pilling and Lynch [39] selected the cooling velocity at 700 degrees Cent. (1290 degrees Fahr.) as a measure of "quenching power" of liquids. Fry[40] in experiments with large axles, based comparisons on the average cooling rates over definite temperature intervals but different intervals were selected for the several coolants used. Mathews and Stagg[41] used the cooling times between 650 and about 370 degrees Cent. (1200-700 degrees Fahr.), which is essentially the same method used by Fry. Matsushita[42] considered the "turning point" or lowering and splitting of the transformations, as indicated by dimensional changes, a measure of the "hardening power," while LeChatelier[43] and Benedicks[44] compared cooling times, generally over the range 700 to 100 degrees Cent. (1290 to 212 degrees Fahr.); Portevin and Garvin[45] used the interval from 700 to 200 degrees Cent. (1290 to 380 degrees Fahr.).

These methods of comparison fall into three main groups: (1)

[39] N. B. Pilling and T. D. Lynch: "Cooling Properties of Technical Quenching Liquids," *Transactions*, A. I. M. E., 62, (1920), p. 2347.

[40] L. H. Fry: "Notes on Some Quenching Experiments," *Journal* of Iron and Steel Institute, 95, (1917), p. 119.

[41] J. A. Mathews and H. J. Stagg: "Factors in Hardening Tool Steel," *Transactions*, A. S. M. E. 36, (1914), p. 845.

[42] T. Matsushita: "Some Investigations on the Quenching of Carbon Steels," *Journal* of Iron and Steel Institute. May meeting, 1923.

[43] H. LeChatelier: "Etudes sur la Trempe de l'Acier," *Revue de Metallurgie*, Vol. 1, (1904), p. 473.

[44] C. Benedicks: "The Cooling Power of Liquids on Quenching Velocities," *Journal* of Iron and Steel Institute, 77, (1908), p. 153.

[45] A. M. Portevin and M. Garvin: "The Experimental Investigation of the Influence of the Rate of Cooling on the Hardening of Carbon Steels," *Journal* of Iron and Steel Institute, 99, (1919), p. 469.

Cooling times over fixed temperature ranges, (2) Cooling velocity at fixed temperatures and (3) the lowering of the transformations in the steels.

The usefulness of the cooling rates around 720 degrees Cent. for comparisons of coolants is due largely to the fact that the rates of cooling in this temperature range determine the extent to which the transformations are lowered or split and hence control in large measure, though not entirely, the degree of hardening produced (with fixed quenching temperatures) in carbon and many alloy steels.

Comparisons of the cooling rates at temperatures around 700 degrees Cent. (1290 degrees Fahr.) will yield about the same information as comparisons of cooling times over the high temperature ranges (say, 800 to 500 degrees Cent.) except that the latter are more likely to be affected by the heat effects of transformations when only partial lowering is produced. However, no one feature of cooling curves can be expected to evaluate all of the salient features of coolants. This should be evident from the data previously described.

2. General Characteristics of Different Coolants

The first requirement for any coolant is that it provide the desired speeds of cooling. However, its adaptability for commercial hardening is dependent upon other factors as well and these include low cost and general availability, permanence with respect to its cooling characteristics in continued use, maintenance of cooling characteristics with moderate temperature changes, ease of handling and safety as regards workmen and equipment. Failure to meet one or more of these latter requirements will not necessarily preclude commercial use but will influence the final selection. Failure to provide the desired speeds of cooling automatically removes a coolant from further consideration.

A wide variety of coolants are encountered in commercial heat treatment practice but the five which are most generally employed are (1) water in baths and sprays, (2) dilute sodium hydroxide solutions, (3) sodium chloride brines, (4) oils or oil-water emulsions, and (5) air. These give a wide range of cooling rates and meet many of the requirements of industrial hardening in a satisfactory manner but special problems often arise which make other coolants attractive. It may therefore be advantageous to correlate the cooling characteristics of some of the commonly used coolants discussed

in previous chapters with those not so generally employed to provide, if practicable, a close gradation in cooling rates over a wide range.

a. Water

Water is probably the most widely used coolant, except air, and fully meets the requirements of low cost and general availability. It is easily handled and safe but its cooling characteristics change somewhat more than those of many oils and some aqueous solutions with change in temperature. With vigorous circulation and provision for cooling the bath, or in the form of sprays, water may be considered to be entirely satisfactory, but with feeble circulation or equivalent slow movement of the heated metal in the bath and no provision for cooling, water may be classed as a wholly unsatisfactory coolant in many cases. As was shown in preceding chapters water will not of itself provide uniform cooling over the surface of heated metal parts under the latter conditions and this lack of uniformity is the source of many difficulties in the hardening of steels.

Water baths at atmospheric temperatures provide cooling speeds somewhat below sodium chloride brines, dilute sodium hydroxide solutions and water sprays but greatly in excess of those of the customary oils. The structures produced at the center of ½-inch cylinders of carbon steels by water quenching, in relation to some other coolants, are shown in Fig. 98 and illustrate the magnitude of some of the differences mentioned when quenching from temperatures between about 810 and 875 degrees Cent. (1490 and 1610 degrees Fahr.)

b. Sodium hydroxide solutions

Dilute sodium hydroxide solutions are useful where cooling speeds in excess of those provided by water baths are desired. Their high cooling speeds are illustrated in Figs. 98 and 99 and in the following tabulation of results obtained with solutions of different concentrations.

% by wgt. of NaOH	Observed Cooling rates at 720°C at center of ½" cylinder, 0.95 C steel deg. C/sec. (875°C quench)	Rockwell C hardness of ½" d. cylinder, 0.95 C steel at center	surface
0	(120–140)	(64)	(64–67)
2.5	215	65	65
5	220	64	67
11.5	220	64	66
16.5	225	64	66

There is apparently a wide range of concentrations which give substantially the same results although this phase of the matter was not fully investigated. However, these solutions offer no difficulties in the maintenance of their cooling characteristics by requiring unusually close control of concentrations, and as was pointed out previously, they are better able than water to compensate for deficiencies in circulation. Their cooling rates are also somewhat less affected by temperature rise than those of water and by their vigorous action upon heated steels they effectively remove scale and so tend to prevent "soft spots" from troostitic areas and tend to promote uniform hardening. Their chief disadvantages are associated with their corrosive nature and they are therefore not as easy to handle as some other rapid coolants. Their cooling characteristics also change with time due to the absorption of carbon dioxide from the air but this is not very troublesome and it is the practice in some plants to make up fresh solutions weekly.

The effectiveness of the sodium hydroxide solutions, where rapid cooling is desired, is due not solely to high rates of temperature change around 700 degrees Cent. (1290 degrees Fahr.) but also to the rapid cooling which is maintained to lower temperatures than is the case with water. This may be disadvantageous in some applications but can be taken care of by "time quenching" in which the metal is removed from the bath when it reaches predetermined temperatures. The sodium hydroxide solutions also "take hold" or "bite" more quickly than water so that there is less lag or a shorter period of comparative quiescence upon immersion and this enables the use of quenching temperatures close to the critical, which is often advantageous.

c. Sulphuric acid

Concentrated sulphuric acid without motion at 20 degrees Cent. was found to be intermediate between the oils and water under similar conditions as is shown in Figs. 98 and 100. Ten to 20 per cent sulphuric acid in water at 20 degrees Cent., either still or in motion at 1 foot per second, was somewhat more rapid as a cooling medium than water but appreciably slower than the sodium hydroxide solutions already discussed. Change in acid concentration from 10 to 20 per cent had a negligible effect upon the cooling curves, resultant center or surface hardness and microstructure of the ½-inch specimens of high carbon steel. The cooling velocities at relatively low

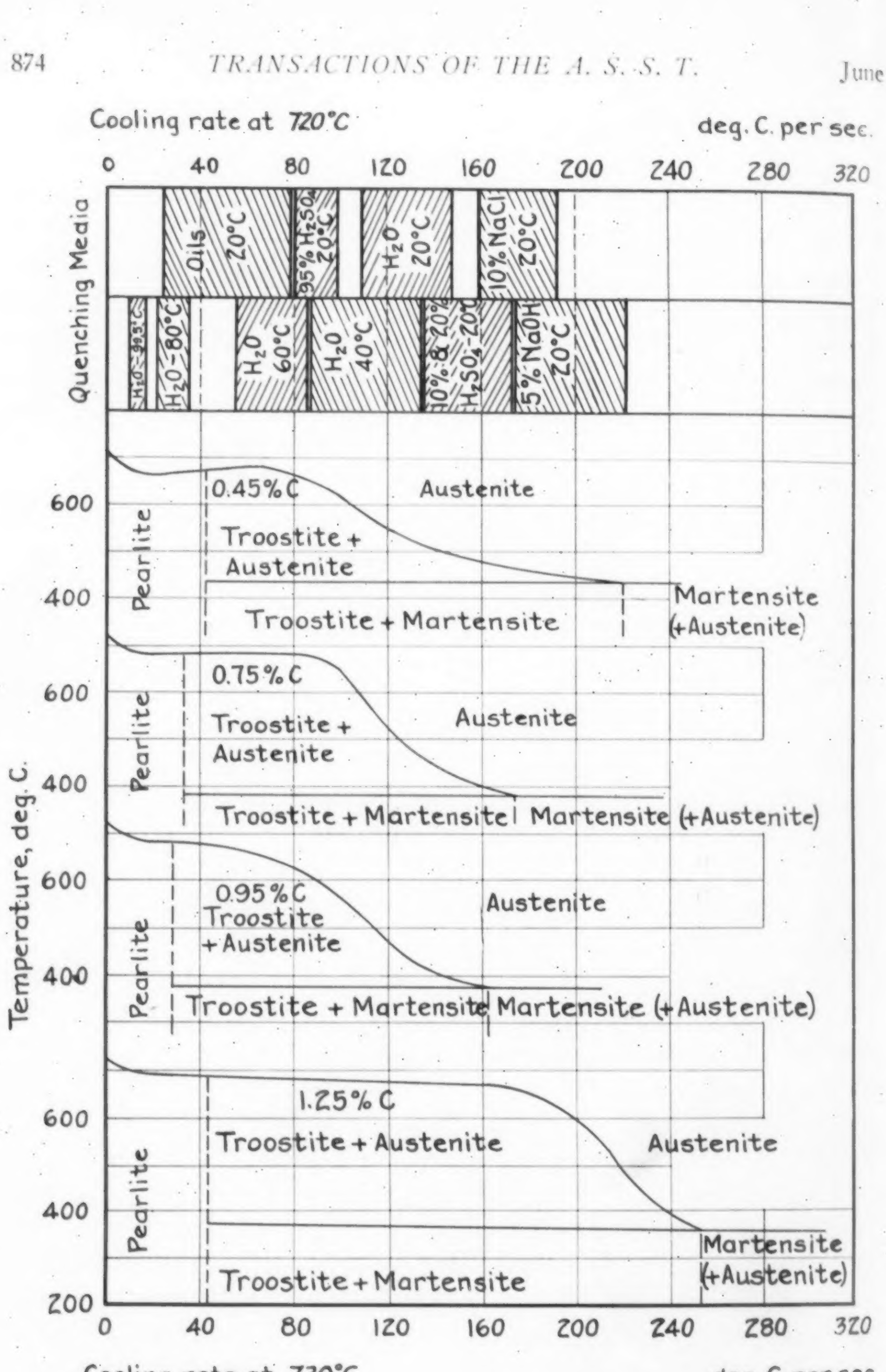

Fig. 98—Relation Between Some Quenching Media for Heat Treatment and Quenching Diagrams for Carbon Steels.

temperatures, in the neighborhood of 200 to 400 degrees Cent. (390 to 750 degrees Fahr.) were slightly higher than those in water and

the magnitude of the increase was about the same as that obtained around 700 degrees Cent. (1290 degrees Fahr.).

The corrosive nature of these solutions is a disadvantage and has restricted their commercial application. The solutions of high concentration are hydroscopic and in time will change in cooling characteristics so that suitable precautions must be taken to maintain the desired concentrations.

d. Sodium chloride brines

Various concentrations of sodium chloride, between 10 per cent and saturation, in water at 20 degrees Cent. (brines) provide cooling rates intermediate between 10 per cent sulphuric acid and 5 per cent sodium hydroxide solutions. However, they overlap the range in cooling rates (Fig. 98) for the somewhat slower dilute sulphuric acid and the more rapid sodium hydroxide but give cooling velocities above those of water. A typical cooling curve for 10 per cent sodium chloride is included in Fig. 100 for comparison with sulphuric acid of various concentrations.

Sodium chloride brines are corrosive as regards equipment but they are not as dangerous to workmen as are the sodium hydroxide solutions, and sulphuric acid. They are widely used industrially and have many of the desirable technical characteristics outlined for the sodium hydroxide solutions. Details will be found in preceding chapters.

e. Calcium chloride brines

The cooling rates provided by calcium chloride brines, with concentrations between about 5 and 20 per cent by weight in water, were about the same as those of the sodium chloride brines, viz:

Concentration % (by wgt.)	Cooling rate at 720°C, at center ½" cylinder, 0.95% C steel deg. C/sec. (875°C quench)	Rockwell hardness, ½" cylinder 0.95% C steel, at Center	Surface
5% $CaCl_2$	190	65	67
10% $CaCl_2$	210	64	64
20% $CaCl_2$	190	66	67
5–10% NaCl	190/215	65/66	67

f. Hydrochloric acid

The few tests made with hydrochloric acid solutions indicated

that 10 per cent hydrochloric acid provides about the same cooling rates as 10 per cent sulphuric acid but as the concentration was increased the cooling speeds in the hydrochloric acid solutions dropped to lower values than those in the sulphuric acid solutions. Comparative data follow:

Concentration % (by wgt.)	Cooling rate at 720°C, at center ½" cylinder, 0.95% C steel, deg. C/sec. (875°C quench)	Rockwell "C" hardness ½" cylinder, 0.95% C steel, at Center	Surface
5% HCl	170	64	64
12.5% HCl	170	64	64
20% HCl	115	63	65
36% HCl	less than 70	44	60
5% H_2SO_4, 10% H_2SO_4, 20% H_2SO_4	160–170	64/66	65/67
30% H_2SO_4	110	63	64
95% H_2SO_4	95	..	..

g. Sodium carbonate solution

Tests made with 10 per cent sodium carbonate in water showed a cooling rate at 720 degrees Cent. (1330 degrees Fahr.) of about 190 degrees per second at the center of ½-inch cylinders of 0.95 per cent Carbon steels quenched from 875 degrees Cent. (1605 degrees Fahr.). The center and surface hardnesses were each 64 on the Rockwell "C" scale. The observed cooling rates were only slightly lower than those of calcium and sodium chloride brines.

h. Soap solutions

Pilling and Lynch[46] showed that only small proportions of soap in water, such as might be introduced by workmen washing their hands in the quenching baths, lowered the cooling rates appreciably. The magnitude of these effects is shown by the results obtained respectively with 0.06 per cent white soap in water and 0.003 per cent of sodium oleate. In quenching ½-inch cylinders of 0.95 per cent carbon steel from 875 degrees Cent. (1605 degrees Fahr.), the center cooling rate, taken at 720 degrees Cent. (1330 degrees Fahr.), in the soap solution was 23 degrees Cent. per sec., and the center and surface hardnesses 32 and 38 respectively on the Rockwell "C" scale. In the sodium oleate solutions the cooling rate was 32 degrees Cent. per second and the hardness 32 and 38. The center cooling curves were quite irregular and indicated a high degree of instability at the surface. Duplication of the experiments

[46]Refer to footnote 59

probably would have given somewhat erratic results but the soap solutions can be said to give reduced cooling speeds in comparison with water.

i. Oils

Time-temperature cooling curves in the six oils referred to in Table II in Chapter I when quenching 0.95 per cent carbon steel cylinders, ½ inch in diameter, from 875 degrees Cent. (1605 de-

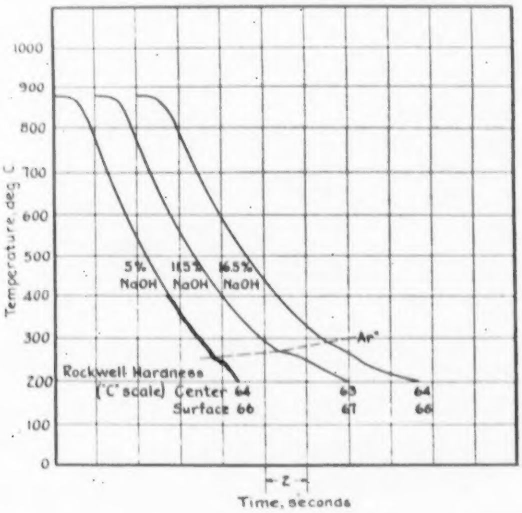

Fig. 99—Time-temperature Cooling Curves Taken at the Center of ½-Inch Diameter Cylinders of 0.95 Per Cent Carbon Steel when Quenched from 875 Degrees Cent. Into Various Sodium Hydroxide Solutions at 20 Degrees Cent., Moving at 1 Foot per Second.

grees Fahr.) are reproduced in Fig. 101. Fig. 98 also shows the approximate range in cooling rates to be expected with varying quenching temperatures between 810 and 875 degrees Cent. (1490 and 1605 degrees Fahr.). As a group, the oils are intermediate in cooling velocities between water at 40 degrees and water at about 90 degrees Cent. However, they all give slow rates of temperature change below about 300 to 350 degrees Cent. (570 to 660 degrees Fahr.) in contrast with the rapid cooling in hot waters, already described. If, as is the case with the 0.95 per cent carbon steel, the formation of martensite occurs around 350 degrees Cent. (660 degrees Fahr.) it may be tempered in part by the slow cooling in the low temperature ranges in the oils. The result in ½-inch cylinders of 0.45 to 1.25 per cent carbon steels is the production of troostite with

Table XXVII
Cooling Rates and Hardnesses Given by Samples of Different Oils

(In order of decrease in cooling rates)

Oil	Sp. Gr. 15° C	Flash point °C	Fire point °C	Absolute Viscosity at 20°C poises	Cooling rate at 720°C, deg. C per Sec.	Rockwell "C" Hardness[1]
Prepared No. 1	.862	185	207	.421	80	44
Prepared No. 2	.874	191	213	.417	68	43
Olive	.917	310	360	.800	67	43
Crude	....	...	...	....	65	43
Cottonseed .... (Wet pressed)	.925	321	360	.795	65	44
Neat's foot	.922	260	327	1.25	60	43
Sperm	.885	260	305	.374	60	44
Prepared No. 3 ...... (new)	....	...	...	....	56	43
after 2-3 yrs. use .	....	...	...	....	52	42
Fish	.933	205	230	.698	55	44
Paraffin	....	...	...	....	53	43
Castor	.963	296	338	10.43	52	43
Rapeseed	....	...	...	....	40	42
Machine	.909	207	240	1.29	39	42
Lard	.917	296	363	.836	34	<39
Transformer	.869	155	182	.218	31	39
Palm	....	224	252	.449[2]	26	<38

[1]Taken at center of 0.95 per cent carbon steel cylinders, ½" diameter by 2" long; when quenched from 875 degrees Cent. into motionless coolants at around 22 degrees Cent.

[2]Taken at 35 degrees Cent.

varying proportions of martensite, and either free ferrite or cementite depending upon whether the steel is respectively hypo- or hypereutectoid. Thus intermediate hardness values are obtained.

Data for these 6 oils are included in Table XXVII along with the results of tests on 10 other oils and the 16 oils are listed in order of decrease in cooling rates. The absence of marked differences in Rockwell hardness values is not inconsistent with the observed differences in cooling rates but is due to the fact that the cooling rates obtained at the center of the ½-inch cylinders employed in the experiments were well below the critical cooling rates and in a range producing no marked changes in the hardness of 0.95 per cent carbon steel, (See Fig. 98.)

This illustrates an important point in the quenching of steels, namely that with some combinations of steel, size and shape and coolant, there is considerable leeway in the speeds of cooling which will produce substantially the same degree of hardness but even so other important properties may not be unaffected. When the conditions are such that the cooling rates approach the critical cooling rates of the steel there is most often little latitude in the choice of coolants and very different results may be obtained from comparatively small differences in the manner of cooling.

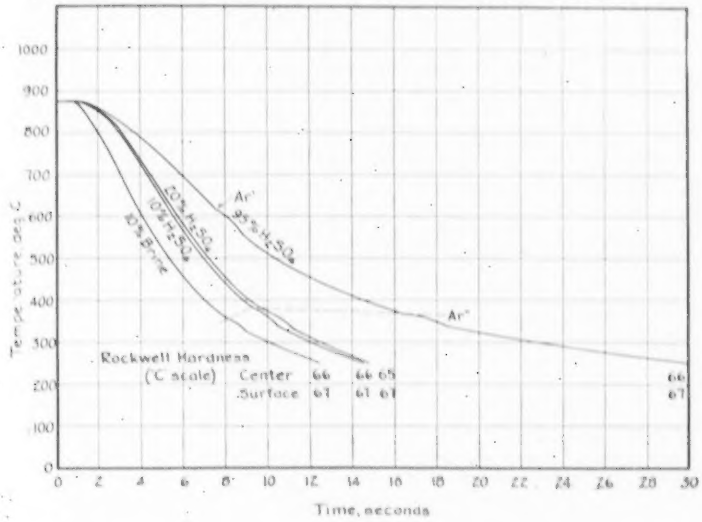

Fig. 100—Time-temperature Cooling Curves Taken at the Center of ½-Inch Diameter Cylinders of 0.95 Per Cent Carbon Steel when Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Sulphuric Acid of Various Concentrations or 10 Per Cent Sodium Chloride Solution Motionless at 20 Degrees Cent.

Prepared oil No. 1, referred to in detail in previous chapters, is of particular interest in that it gave the highest cooling rates at high temperatures of any of the oils tested.

It is also of interest to note that the two oils giving the most rapid cooling at high temperatures were both proprietary quenching oils which suggests that faster cooling rates are desired in quenching oils in the industry.

Neat's foot and sperm oils gave the same moderately rapid cooling at high temperatures and both also showed relatively rapid cooling at low temperatures.

The slowest cooling at high temperatures was obtained in palm oil but low rates of temperature change were also observed in lard and transformer oils.

Full information is not available regarding the permanence of the various oils tested but prepared oils Nos. 1 and 2, which are used industrially, are known to be satisfactory in this respect. Tests were made of a sample of prepared oil No. 3 which was reported to have been taken from a bath in use 3 years with only sufficient additions of new oil to keep the required level in the tank and, as is shown in Table XXVII, there was only a slight decrease in the cooling rates and this was probably within the limits of reproduci-

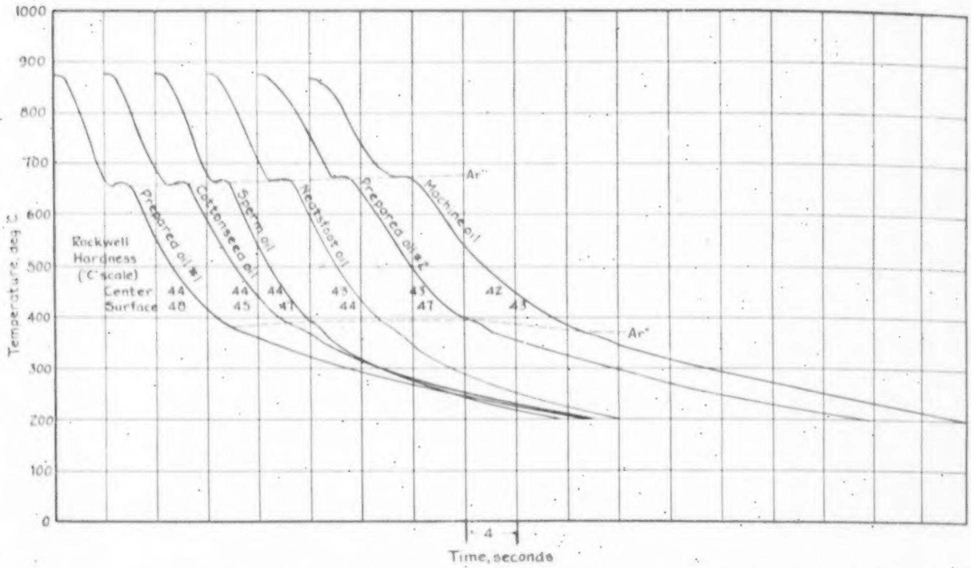

Fig. 101—Time-temperature Cooling Curves Taken at the Center of ½-Inch Diameter Cylinders of 0.95 Per Cent Carbon Steel when Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Various Oils Motionless at 20 Degrees Cent.

bility in the experiments. Prepared oil No. 3 can also be considered to have a desirable degree of permanence.

Fire hazards are indicated roughly in Table XXVII by the reported flash and fire points of the different oils. Cost factors will not be discussed.

As a group the oils show smaller changes in cooling speeds with change in temperature than water or aqueous solutions but not all oils will show such small differences as those shown by the two prepared quenching oils studied at different temperatures as described in Chapter V.

j. Heated salt or metal baths

Cooling curves were not obtained in heated salt or metal baths but their experimental application in the hardening of carbon and alloy steels can be made the basis of a few general comments. Molten salt or metal baths are sometimes useful as coolants since they provide means whereby the hardening transformations may be caused to take place at different temperatures and there is some evidence that the properties of steels may sometimes be improved and hardening troubles avoided by such methods of quenching. For example, it has been possible to improve the toughness of hardened alloy steels, at high hardnesses, by quenching in molten lead-tin-bismuth-cadmium alloys at temperatures around 250 degrees Cent. (480 degrees Fahr.).

The molten metal baths cool more rapidly than the salt baths but neither will produce full hardness (R_c around 64) in carbon steels except in very small sections. However, the molten metal baths often give sufficiently rapid cooling to produce high hardness in low alloy tool steels, but quenching in such a manner is somewhat less attractive commercially than quenching in the aqueous solutions or oils if these latter coolants will give the desired results.

3. Temperature Distribution in Water, No. 2 Oil and Air

The temperature distribution when cooling in different media is a matter of practical importance since the hardening transformations in steels are accompanied by volume changes which can create stresses of appreciable magnitude and which often result in fracture. The stresses developed depend upon the temperature distribution as well as upon many other variables and the solution of problems in this field becomes complex. While a study of temperature distribution was beyond the scope of the described tests differences between surface and center temperatures can be considered to advantage in the general comparisons of coolants.

a. Comparison of experimental and derived cooling curves[47]

The problem of determining the temperature at any point in a body as a function of time, under a given set of conditions, is one which is sometimes capable of solution mathematically. It is a matter of some interest to determine if these mathematical treatments can be applied to the practical problem of temperature distribution during quenching.

The process of solving such problems is one of finding a solution of the general differential equation of heat conduction which fits a set of "boundary conditions" determined by the problem under consideration. There are two well known solutions which are based on assumptions which should give a fair approximation to the facts. Both of these will be discussed in the following paragraphs.

The general differential equation is

$$\frac{du}{dt} \quad \alpha^2 \left(\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2} \right) \tag{11}$$

[47]The computations used in the discussion in this part of the paper were made wholly by Dr. Cook. See footnote (4) Chapter I.

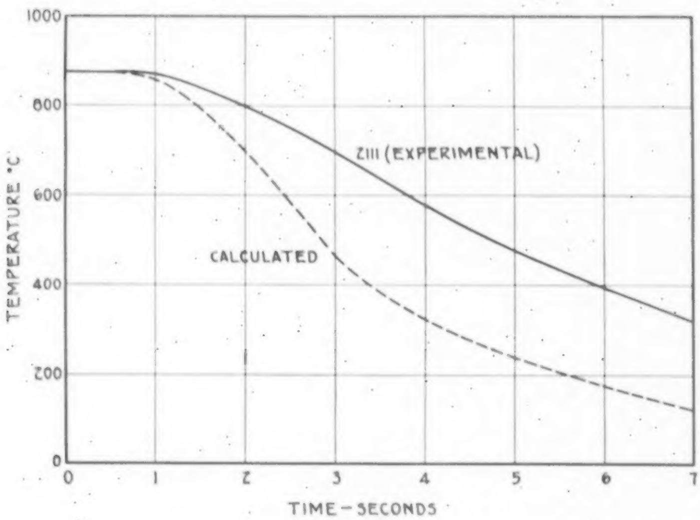

Fig. 102—Experimental Center Cooling Curve for a 1-Inch Sphere Quenched in a Water Spray Under 110 Pounds Per Square Inch Water Pressure Compared to the Cooling Curve Calculated on the Assumption of Instantaneous Drop to Coolant Temperature at the Surface. See Text for Details (First Set of Assumptions).

Here u is the temperature, t, the time, and x, y and z the space coordinates; a^2 is the diffusivity of the material and is defined as $\frac{\lambda}{sd}$ where λ is the thermal conductivity, s, the specific heat, and d, the density.

The diffusivity is assumed constant although it is known to be a function of temperature. Furthermore, there is little information available on the values of diffusivity for steels over the range 20 to 875 degrees Cent. (65 to 1605 degrees Fahr.), as has already been pointed out. It is likewise, assumed that there is no heat developed within the material which means that the heats of transformations are neglected, but this should lead to serious errors only in cases where large heat effects are observed. The heats of transformations can be neglected when cooling small pieces rapidly.

The first of the solutions of the general equation of heat conduction assumes the following "boundary conditions"; the temperature of the body is uniform at the time of quenching and the surface temperature falls instantly to the temperature of the coolant. As seen from the experiments already described, this latter assumption is a good approximation only in the case of the most drastic coolants such as pressure spray quenching or for bodies of low diffusivity.

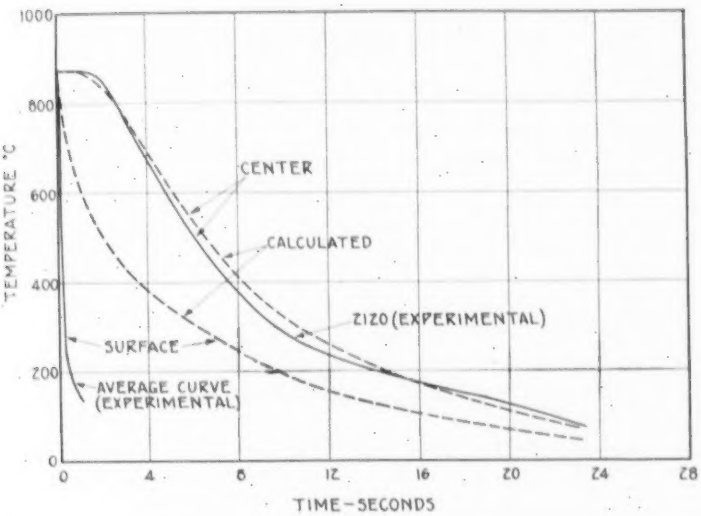

Fig. 103—Experimental Center and Surface Cooling Curves for 1-Inch Spheres Quenched in a Water Bath Compared to Cooling Curves Calculated on the Assumption of Newton's Law of Cooling. See Text for Details (Second Set of Assumptions).

Fig. 102 shows a cooling curve for the center of a 1-inch sphere computed on these assumptions, compared to the experimental curve obtained in the drastic pressure spray quenching. The value of diffusivity used in the calculations was 0.07 cm.^{2} sec.$^{-1}$, and is assumed to be a fair average value over the entire cooling range. This value gives a computed cooling curve which is much faster than the experimental curve. Lower values of diffusivity would bring the two curves closer together but such lower values do not seem justified in the light of present information.

The second solution mentioned above, assumes that the surface of the body loses heat at a rate proportional to the difference in temperature of the surface and the coolant. The proportionality constant is called surface conductivity and depends upon the coolant and probably also many other factors. It does not seem reasonable that so simple a law should hold for cooling in liquids[48] where the range of temperature is so large as in the quenching of steels but the surface temperature curves computed on this assumption have the same general characteristics as the experimental curves.

The results of such calculations are shown in Figs. 103 and 104.

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[48]The experiments of H. Worthington and C. B. Malone: "Convection of Heat from Small Wires in Water," *Journal*, Franklin Institute, Vol. 184, p. 115, (1917), indicate that the rate of dissipation of heat probably does not increase proportionally with rise in temperature of the body immersed in the liquid. The rate of increase of dissipation is faster than this law would indicate.

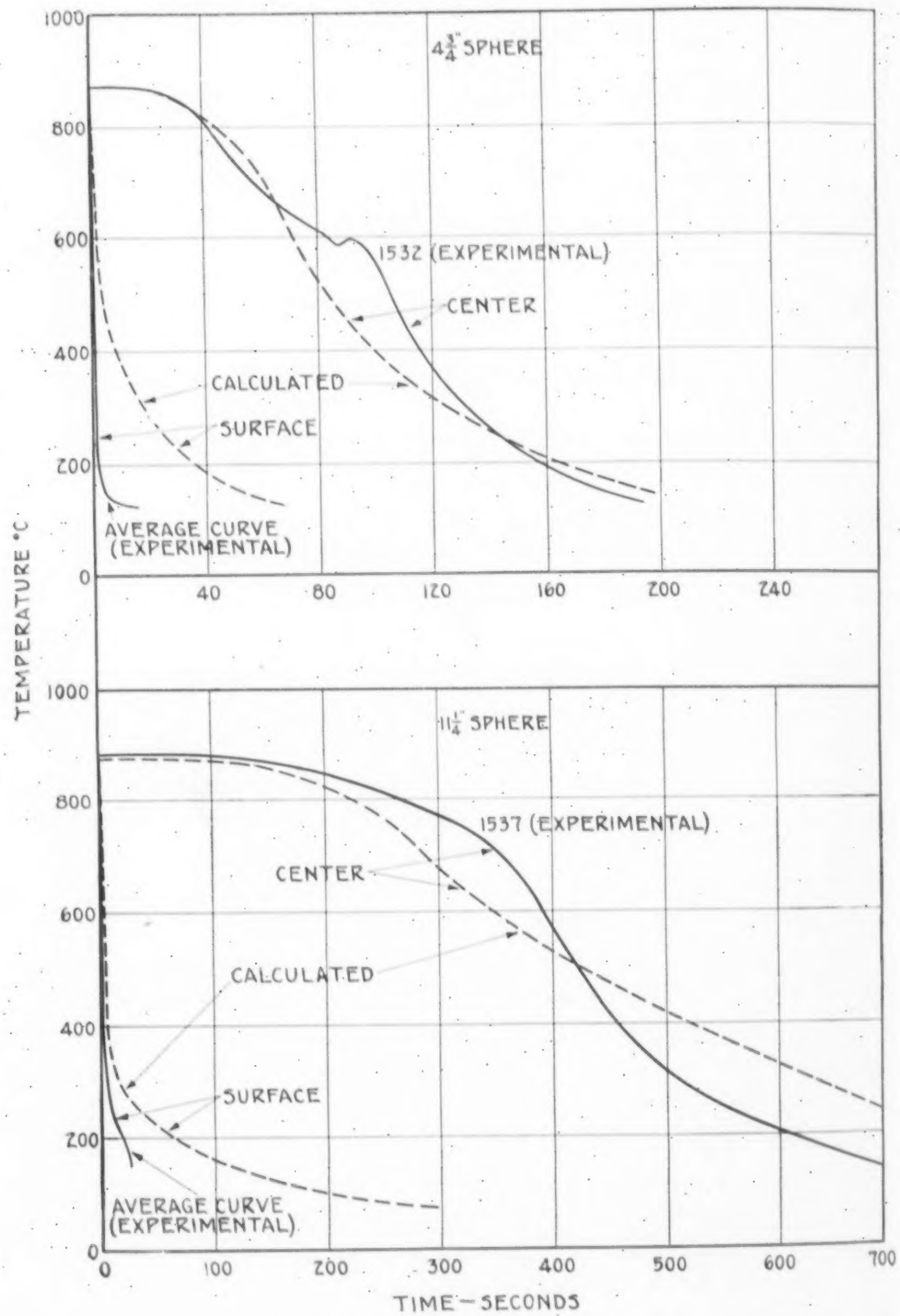

Fig. 104—Experimental Center and Surface Cooling Curves for 4¾ and 11¼ Inch Spheres Quenched in a Water Bath Compared to Cooling Curves Calculated on the Assumption of Newton's Law of Cooling. See Text for Details (Second Set of Assumptions).

A value of surface conductivity (1.18 cm^{-1}) was chosen which gave a good approximation to the experimental results for the center of the 1-inch sphere and this value was then used in computing the center and surface temperatures of the 4¾ inch and 11¼ inch spheres. The derived and experimental center cooling curves show fairly good agreement but the surface curves are very different for the 1-inch sphere. However, the experimental and derived surface curves show closer agreement as the size of sphere is increased.

A possible explanation of the differences between the computed and experimental cooling curves is that the experimental curves represent cooling over only a small area of the surface. Certain portions of the surface may cool very slowly at first as shown by "hot spots" which have been observed to remain subsequent to the introduction of the sample into the coolant. These would make the average temperature of the whole surface somewhat higher than the temperatures observed experimentally at one location. If it were practicable to take account of these effects, the experimental and computed cooling curves might be brought closer together.

The liberation of heat during transformations is another factor which has been neglected in the computations and which tends to increase the differences between the computed and experimental cooling curves. The surface areas pass through the transformation temperatures before the interior and conditions may be encountered where the heat of transformations from the surface metal will retard the center cooling before the center has reached the transformation temperature range. Examination of the experimental cooling curves shows that the cooling rates are not very different from the calculated values but there is an initial lag which is greater for the larger sizes.

Evidently such calculations as have been described are of limited practical value. More accurate predictions would require a more accurate knowledge of the true laws of cooling and must also take into account the heat of transformations. The computations based on the simple assumptions already stated are extremely tedious but may be made quite simply with the aid of tables computed by Gröber.[49]

[49] H. Gröber, Die Erwärmung und Abkühlung einfacher geometrischer Körper, Zeit. d. Ver. Deutscher Ingenieure, Vol. 69, p. 705 (1925).

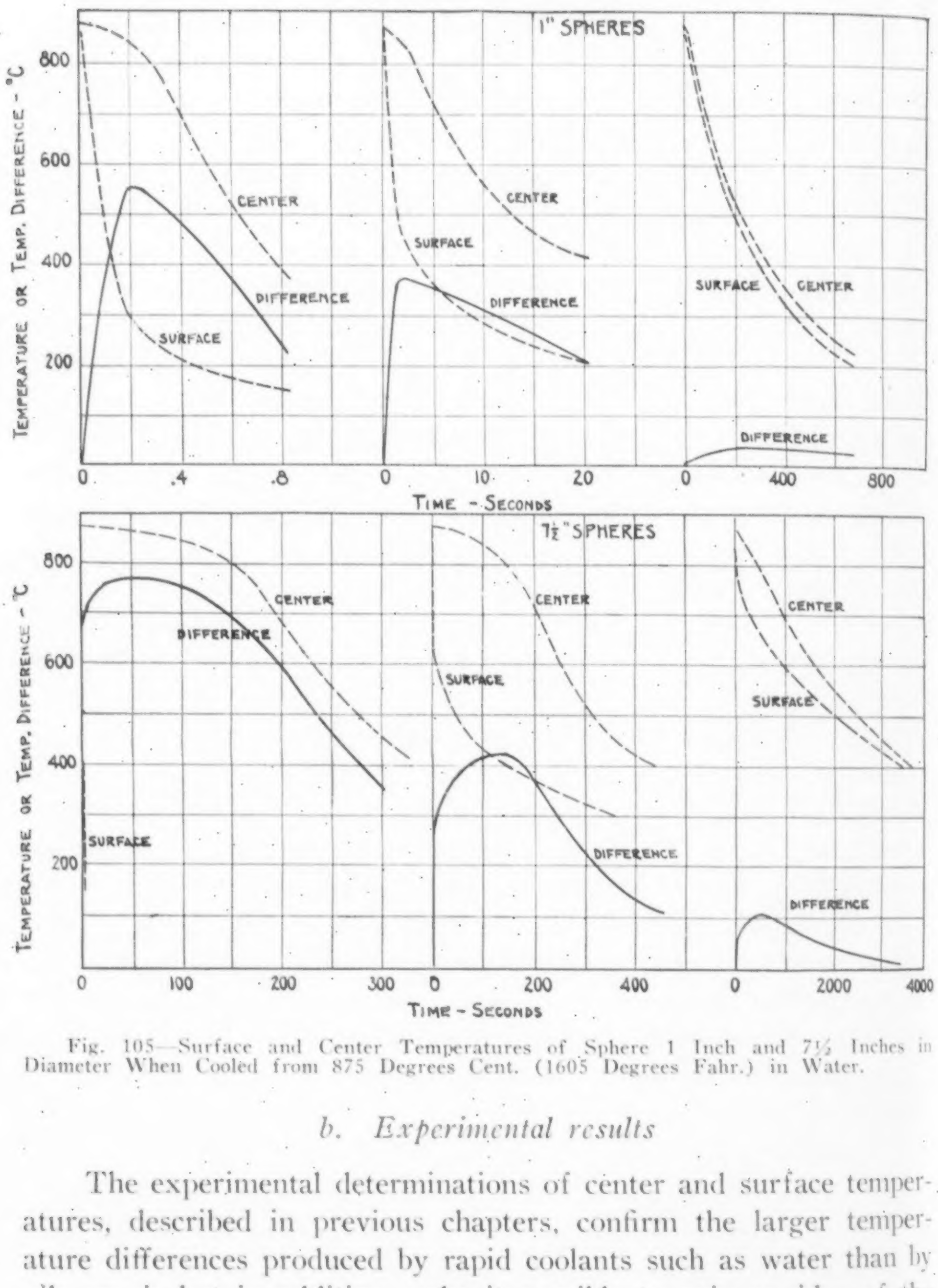

Fig. 105—Surface and Center Temperatures of Sphere 1 Inch and 7½ Inches in Diameter When Cooled from 875 Degrees Cent. (1605 Degrees Fahr.) in Water.

b. Experimental results

The experimental determinations of center and surface temperatures, described in previous chapters, confirm the larger temperature differences produced by rapid coolants such as water than by oils or air but in addition make it possible to gain an idea of the magnitude of the differences involved for both small and large specimens. For convenience, the approximate cooling curves of spheres, 1 inch and 7½ inches in diameter, are reproduced in Fig. 105 together with the differences between surface and center temperatures as a function of time.

The center temperatures given in Fig. 105 for the water and the No. 2 oil were determined in the motionless liquids but no appreciable errors are introduced, for present purposes, if these are considered to represent approximately the conditions of slow motion (3 feet per second) under which the corresponding surface temperatures were determined.

In Fig. 105 the magnitude of the maximum temperature differences (surface and center temperatures) is shown to be about 450 to 750 degrees Cent. in the water, 375 to 425 degrees Cent. in the No. 2 oil and roughly 25 to 100 degrees Cent. in still air when the 1-inch and 7½-inch spheres were cooled from 875 degrees Cent. (1605 degrees Fahr.). As might be expected the maximum temperature differences were larger in the large sphere than in the small one but in both sizes the time-difference curves of Fig. 105 had the same general form and the differences between surface and center temperatures were larger in water than in the oil and much larger in the oil than in air.

The data in Fig. 105 may be considered to be characteristic in a general way of three important groups of coolants, (1) rapid coolants such as water and aqueous solutions, (2) coolants giving intermediate rates of temperature drop, such as oils and, (3) air. The changes with time will vary in magnitude with the different coolants in each group and with the size and shape of the piece, initial temperature of cooling and other variables but the general trends appear to be determined largely by the rate of temperature drop at the surface.

The more rapid the cooling at the surface the lower is the surface temperature at which the maximum temperature differences occur under otherwise comparable conditions. Since the plasticity of steels decreases generally with a decrease in temperature, the surface of the steel will less readily be able to deform and relieve the stresses set up by the volume changes accompanying the hardening transformations when cooling rapidly as in water than when cooling more moderately as in oil or still more slowly in air.

These features are well known and Fig. 105 is given principally to show the magnitude of the temperature differences as determined directly by experiment for three of the important coolants used in heat treatment processes.

It is not unreasonable to assume that the stresses set up in the rapid coolants such as water will be of a different order of magnitude

than those set up under otherwise comparable conditions in more moderate coolants such as oils and these differences have been made the basis of an explanation of the retention of more austenite on oil quenching than in the more rapid water quenching as observed by Mathews.[50]

These matters deserve attention and could to advantage be made the basis of valuable research but direct experimental attack would be difficult at this time. In this connection F. R. Palmer has suggested that the large temperature differences encountered in rapid coolants be made to work for, instead of against the steel treater. By controlling the flow and contact of the coolant with the heated steel (jets and flushing equipment) it should be possible in many cases to modify the stress distribution in dies and tools so that the residual stresses will be opposite in nature to those imposed in service and give the metal the equivalent of higher strength.[51] Such methods of control are known to have been used to advantage and to have resulted in very large increases in the life of quenched steel parts in service.

Further Acknowledgements

In addition to the acknowledgments recorded in the introduction to this paper to former associates at the Bureau of Standards, the author is indebted to J. W. Sands of the Development and Research Department of the International Nickel Company for assistance in preparation of the manuscript and for carrying out some of the tests (Chapters VI and VII) which were not previously reported.

[50]J. A. Mathews: "Austenite and Austenitic Steels," *Transactions*, A. I. M. E., Vol. 71, 1925, p. 568.

[51]So far as is known detailed applications have not been published by F. R. Palmer, the data referred to having been included in lectures before local chapters of the A. S. S. T. See Transactions, American Society for Steel Treating, Vol. 17, April 1930, p. 27 and 28 of section on news of chapters.

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ALLOY STEEL

Modern Development in High-Grade Steel Making (Neuzeitliche Entwicklung des Edelstahls) P. Goerens. *V. D. I. Zeit. (Berlin)*, vol. 74, no. 10, Mar. 8, 1930, pp. 297-302, 13 figs.

General survey of recent progress in steel-making methods; properties of high grade steels, with special reference to non-corrosive and heat-resisting steels; special uses for high-grade steels in metallurgy, machine construction, etc.; case-hardening processes.

ANTI-CORROSIVE. Copper Steel—Rustproofing of Steel Materials, M. E. McDonnell. *Far East Rev. (Shanghai)*, vol. 26, No. 1, Jan. 1930, pp. 42-44, 2 figs.

Work of Research Department of Pennsylvania Railroad System concerning steel rusting and corrosion, and protection measures; description of test for examination of sheet-steel life; variation curve in rate of corrosion of steel; table showing cost of steel-car maintenance as affected by resistance to rust.

HEAT RESISTING. Alloys that Resist Heat, T. H. Nelson. *Iron Age*, vol. 125, no. 8, Feb. 20, 1930, pp. 578-580, 2 figs.

Notes on strength at high temperature, corrosion, and oxidation, many phenomena are debatable; roles of nickel, chromium, and silicon. (Concluded.)

ALLOY STEEL ANALYSIS

Influence of Different Alloying Elements on Critical Points of Carbon Steel (Der Einfluss verschiedener Legierungselemente auf die kritischen Punkte von Kohlenstoffstahl), A. Merz. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 9, Mar. 1930, pp. 587-596, 22 figs.

Description of improved Chevenard dilatometer; investigation of electrolytic iron, carbon, nickel, chromium, tungsten, silicon, manganese, and chromium-nickel steels; change of hysteresis by different alloys with and without carbon.

ALLOY STEEL CASTINGS

Alloys in Steel Castings, F. A. Melmoth. *Metallurgia (Manchester)*, vol. 1, no. 2, Dec. 1929, pp. 73-74.

Increased severity of working conditions widens need for alloy steel castings; author suggests that while present methods of purchasing steel castings are of type that demands so much weight for smallest possible sum of money, more equitable basis and one designed to hasten progress would be to buy service and satisfaction at higher rate per unit of weight.

Alloyed Steel Castings in Theory and Practice (Legierter Stahlguss in Theorie und Praxis), A. Rys. *Stahl und Eisen (Duesseldorf)*, vol. 50, no. 14, Apr. 3, 1930, pp. 423-438, 56 figs.

Improvements of ingot steel to meet present mechanical, physical and chemical requirements, by addition of alloying elements; investigation of different alloy-steel castings to determine strength, high-temperature resistance, effect of heat treatment, endurance, corrosion resistance, impact hardness, etc.; magnetic and non-magnetic acid- and heat-resisting steels.

ALLOYS

Electrolysis of Molten and Solid Alloys (Ueber die Elektrolyse geschmolzener und auch fester Legierungen), R. Kremann. *Berg und Huettenmaennisches Jahrbuch (Vienna)*, vol. 78, no. 1, Feb. 15, 1930, pp. 1-11, 5 figs.

Discussion of theories and experimental investigation of electrolysis of solution of metal alloys; influence of current density, temperature, distance between electrodes, and synthesis of alloys; electrolysis of solid alloys. Bibliography.

ANTI-CORROSIVE. Corrosion Resisting Alloys for Pulp and Paper Mills, W. M. Mitchell. *Paper Trade Jl.*, vol. 90, no. 8, Feb. 20, 1930, pp. 155, 157 and 159.

Selection of metals for construction of plant equipment for use in handling corrosive materials is problem affecting many processes, and is always one of extreme importance; corrosion phenomena; corrosion in paper mills; chromium alloys. Paper presented before T.A.P.P.I.

HEAT TREATMENT. Refining of Alloys (Die "Verguetung" oder "Veredelung" von Legierungen), W. Guertler. *Zeit. fuer Metallkunde (Berlin)*, vol. 22, no. 3, Mar. 1930, pp. 78-84, 16 figs.

Improvement of properties of alloys by heat treatment is discussed; method of treatment; influence of temperature and time; significance of X-ray space-grid research for explanation of refining processes.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders.

HEAT TREATMENT. Heavy Metal Alloys Capable of Heat Treatment (Verguetbare Schwermetall - Legierungen), G. Masing. *Zeit. fuer Metallkunde (Berlin)*, vol. 22, no. 3, Mar. 1930, pp. 90-94, 7 figs.

Prospects of finding alloys which can be subjected to heat treatment are discussed; of greatest technical importance at present time are Heusler and Corson alloys, and alloys containing beryllium; refining of copper-bearing iron alloys, carbon-iron alloys, and eutectoid disintegration of zinc-aluminum alloys.

ALUMINUM ALLOYS

HEAT TREATMENT. Aluminum Alloys Capable of Heat Treatment (Verguetbare Aluminium-Legierungen), W. Fraenkel. *Zeit. fuer Metallkunde (Berlin)*, vol. 22, no. 3, Mar. 1930, pp. 84-89, 15 figs.

An example of simple alloy, aluminum with slight copper content, and its heat treatment are discussed; phenomena observed with treatment at ordinary, elevated, and fluctuating temperature; theory of treatment is discussed; main types of important aluminum alloys and their transformation to other and to more complicated systems are described.

X-RAY ANALYSIS. X-Ray Analysis of Refined Aluminum Alloys (Die Veredelung einer Aluminiumlegierung im Roentgenbild), V. Goeler and G. Sachs. *Mitteilungen der deutschen Materialpruefungsanstalten (Berlin)*, no. 10, 1930, pp. 33-43, 25 figs.

Results of X-ray analyses of aluminum alloys which have been subjected to different heat-treating processes.

ALUMINUM-COPPER ALLOYS

Ultralumin (Ultralumin), F. Bollentrath. *Luftfahrtforschung (Munich)*, vol. 6, no. 1, Dec. 12, 1929, pp. 18-32, 28 figs.

Results of investigation made at Aerodynamic Institute of Technology on metal placed on market under trade name of Ultraluminum U II; it is aluminum-copper alloy, free from magnesium, strength of which can be increased by artificial aging; melting point, 645 deg. cent.; forging temperature, 460 to 480 deg.; heat-expansion coefficient, 0.000022; temperature resistance coefficient 0.00218; modulus of elasticity, 6900 to 7300 kg. per sq. mm.

ALUMINUM METALLOGRAPHY

Some Developments in Aluminum Metallurgy, N. C. Ashton. *Foundry Trade Jl. (Lond.)*, vol. 42, no. 703-704, Feb. 6, 1930, pp. 101-105 and 108, and (discussion) Feb. 13, 1930, pp. 119-120, 13 figs.

Feb. 6: Unsoundness due to presence of dissolved gases and lack of proper fluidity and feeding are main difficulties in casting; use of secondary aluminum alloy ingots; process of melting borings; composition specifications; short freezing range and soundness; grain size modification; effects of chlorine treatment; modification by boron trichloride; conservation of strength after boronization; zinc alloys.

BEARING METALS

BRONZE. Phosphor Bronze for Bearings, H. C. Dews. *Metallurgia (Manchester)*, vol. 1, no. 1, Nov. 1929, pp. 21-23, 3 figs.

Range of composition of phosphor bronzes useful for bearings; adjustment of contents to suit conditions; effects of lead, of nickel, and of zinc; discussion of microstructure.

BEARINGS

Bearing Metals and Bearings, W. M. Corse, New York; Chemical Catalog Co., 1930 (American Chemical Society Monograph series), 383 pp., $7.00.

After review of history and fundamental principles involved in selecting bearing metals, book gives bibliography of articles and books on bearings, metals, sliding-contact bearings, frictions, and lubrication which appeared from 1920 to 1930, amounting to over 1000; good abstracts of 234 of more significant papers are given; tables of properties of bearing metals, and author and subject indexes complete this very useful work of reference. Eng. Soc. Lib., N. Y.

BEARINGS, BALL

MANUFACTURE. Condition of Material Watched Closely in Ball Bearing Manufacture. *Iron Age*, vol. 125, no. 10, Mar. 6, 1930, pp. 703-706, 3 figs.

At Hartford plant of S. K. F. Industries, Inc., material tests begin with receipt of bars, tubes, and other raw material, and are made at various stages of manufacture, up to final assembly; inspections are for most part by means of hardness tests; details of automatic lathe department; hardening room; quenching tanks equipped with fire extinguishers.

STEEL. Materials Control in Manufacture of Ball-Bearing Steel (Im materialkontroll vid tillverkning av kullagerstal), J. Larsson. *Jernkontorets Annaler (Stockholm)*, vol. 85, no. 1, 1930, pp. 27-42, 9 figs.

Ball-bearing steel can only be judged by practical performance tests on finished balls; steel must be homogeneous and free from slag; experience shows that shelling is caused by deposits of slag on or directly under surface of balls or rings; steel must be free from flakes and reduction of carbon on surface and annealed in satisfactory manner.

BRONZE CASTINGS

Unsoundness in Bronze Castings, E. J. Daniels. *Inst. of Metals—Advance Paper*, no. 515, for mtg., Mar. 12, 13, 1930, 18 pp., 7 figs.

Effect of some pure gases on soundness of bronze, and of casting in sand molds of metal subjected to various melting treatments, is described, and tentative explanation of cause of unsoundness occurring in practice is suggested. Bibliography.

CAST IRON

HIGH TEST. Technological and Metallurgical Fundamentals of High-Test Cast Iron (Die giessereitechnischen und metallurgischen Grundlagen des hochwertigen Gusseisens), A. Achenbach. *Giesserei (Duesseldorf)*, vol. 17, no. 11, Mar. 14, 1930, pp. 245-251, 11 figs.

Properties of cast iron which deviate from those of steel are attributed to nature of gray-iron structure, from which conclusions are drawn and means suggested of im-

proving mechanical properties by grain refinement and prevention of internal defects in casting.

HIGH TEST. High-Duty Cast Irons, A. E. McRae Smith. *Foundry Trade Jl. (Lond.)*, vol. 42, nos. 701, 702 and 703, Jan. 23, 1930, pp. 59-60, Jan. 30, 1930, pp. 83-87 and (discussion) Feb. 6, 1930, pp. 99-100, 15 figs.

Jan. 23: Methods of securing equalized tensile strength in cast iron; annual fire-bar wastage deplorable; problem of southern foundries; double process iron. Jan. 30: Classification of special irons; potentialities of steel-mix irons; cupola practice for high-duty iron; carbon control; newer melting methods; Poumay cupola; alloy cast irons; nickel chrome irons; Lanz perlit irons.

CAST IRON PROPERTIES

The Pig Iron Function in Cast Iron and Wrought Iron Manufacture, J. E. Fletcher. *Iron and Steel Industry (Lond.)*, vol. 3, no. 5, Feb. 1930, pp. 133-136, 5 figs.

Mechanical properties of wrought iron and slag function; oxidation of cast iron in open hearth furnaces and resulting slags; teaching of microstructure of cast iron. (Concluded.)

CAST IRON SOLIDIFICATION

On the Change of Volume of Cast Iron During Solidification, K. Honda, T. Kase and Y. Matsuyama. *Tohoku Imperial Univ.—Sci. Reports*, vol. 18, no. 5, Dec. 1929, pp. 699-714, 4 figs.

Writers previously studied volume change in cast iron during solidification and found very important results; same change in many samples of cast iron was redetermined with greater accuracy in order to confirm results previously obtained; method and apparatus of measurement were same as those used before with some improvements; result of present experiment has confirmed that of former investigation. (In English.)

CAST IRON TESTING

Mass and Skin Effects in Cast Iron, Swift. *Foundry Trade Jl. (Lond.)*, vol. 42, nos. 702 and 703, Jan. 30, 1930, pp. 79-80, Feb. 6, 1930, pp. 106 and 108, 6 figs.

Jan. 30: Extent to which mechanical properties of cast iron are affected by transverse section of bar as cast, and by machining to various depths below skin; B.E.S.A. grey iron specifications; tests for tensile strength, crushing strength, Brinell and scleroscope hardness and resistance to abrasion. Feb. 6: Results of tensile and compressive tests carried out upon bars after their diameters had been reduced by turning; metallurgical aspects.

CASTINGS

MACROSTRUCTURE. Macrostructure of Cast Alloys: Effect of Turbulence due to Gases, R. Genders. *Inst. of Metals—Advance Paper*, no. 519, for mtg., Mar. 12-13, 1930, 6 pp., 7 figs.; see also *Engineering (Lond.)*, vol. 129, no. 3348, Mar. 14, 1930, pp. 357-358, 7 figs.

Communication forms additional section to previous paper in which work was described having object of making possible more general interpretation of macrostructure of cast metals; observations indicate that when ingot of small thickness is cast in mold prepared by application of coating or "dressing" of volatile material, macrostructure is considerably modified by turbulence resulting from evolution of gases between mold and liquid metal.

CHROMIUM

Sources and Applications of Chromium, *Heat Treating and Forging*, vol. 16, no. 3, Mar. 1930, pp. 343-344.

Expansion in consumption of chromium, begun in 1922, has continued in recent years; shipments of chromite from mines in United States in 1928; development of successful electrical smelting methods for making stainless steels direct from chromite and iron ore; importation of chromite; estimated world production of chromite in 1928 was about 449,000 metric tons, increase of 41,000 tons over 1927.

CHROMIUM STEEL

Some Structural Characteristics of High Chromium Irons and Steels, J. H. G. Monypenny. *Metallurgia (Manchester)*, vol. 1, nos. 2 and 3, Dec. 1929, pp. 61-64, and Jan. 1930, pp. 115-118, 22 figs.

Dec.: Discussion of effects produced on structure and properties of steels by addition of chromium, above 12 per cent.; microstructural changes produced on quenching. Jan.: Three groups of structural changes are discussed; most serious defect of high-chromium irons is notch brittleness; stainless irons; production of decarburized skin when heated to high temperatures.

CHROMIUM-NICKEL STEEL

ANNEALING. Elimination of Carbide in Annealing of Rustless, Non-Magnetic, Chromium-Nickel Steel (Die Carbidausscheidung beim Gluehen von nichtrostendem unmagnetischen Chromnickelstahl), B. Strauss, H. Schottky, and J. Hinnueber. *Zeit. fuer anorganische und allgemeine Chemie (Leipzig), (Special number)*, vol. 188, Mar. 8, 1930, pp. 309-324, 17 figs.

Experimental studies of heat treatment of special Krupp steel alloy known as V 2 A; effect of carbide elimination on mechanical properties and on resistance to corrosion; artificial production of intercrystalline corrosion; method of carbide preparation.

COBALT-COPPER ALLOYS

An Air-Hardening Copper-Cobalt Alloy, C. S. Smith. *Min. and Met.*, vol. 11, no. 280, Apr. 1930, pp. 213-215, 4 figs.

Copper alloy containing between 1 and 5 per cent cobalt is soft when quenched, but can be hardened by proper re-annealing.

COPPER ALLOYS

METALLOGRAPHY. Metallographie der Technischen Kupferlegierungen, A. Schimmel. Berlin, Julius Springer, 1930, 128 pp., 19 r.m.

Handbook on metallography of commercial alloys of copper, which aims to provide book for testing laboratory similar to those available on iron and steel; micrographic and monographic methods of examining these alloys are given and interpretation of results explained; theoretical considerations are sub-

ordinated to practical use. Eng. Soc. Lib., N. Y.

P.M.G. P.M.G Metal for Replacing the Bronzes, M. A. Hunter. *Heat Treating and Forging*, vol. 16, no. 3, Mar. 1930, pp. 344-345.

Hardened copper alloy can be utilized in all situations where high tensile strength is required; alloy as cast contains as its major constituents 2 per cent of iron and 3.4 per cent of silicon with 2 per cent of zinc; hardening is presumably due to presence of iron silicide; this compound dissolves at high temperatures in molten copper; on cooling, iron silicide precipitates from solid solution in such manner as to increase hardness of solidified alloy; metal can be readily forged hot.

P.M.G. Promotes New Copper Alloy. *Iron Age*, vol. 125, no. 10, Mar. 6, 1930, p. 727, 2 figs.

P.M.G. metal, a hardened copper alloy was developed as substitute for phosphor bronze, manganese bronze, and gun metal by technical staff of Vickers-Armstrong, Ltd., at naval construction works at Barrow-in-Furness, England; it has superseded Admiralty gun metal wherever specifications and purchasers permit; cast alloy contains as its major constituents 2 per cent of iron and 3.4 per cent of silicon with 2 per cent of zinc.

CORROSION

New Observations on the Asymmetry of Corrosion Forms Obtained by an Active Isotropic Liquid (Nouvelles observations sur la dissymétrie des figures de corrosion obtenues par un liquide isotrope actif), L. Royer. *Académie des Sciences—Comptes Rendus (Paris)*, vol. 189, no. 22, Nov. 25, 1929, pp. 932-933.

Crystallographic study of colamine, giving results of corrosion with various organic acids, active and inactive, and showing effect on crystal structures; experiments with tartaric acid treated with various organic acids and alcohols are also described.

CRYSTALS

PLASTICITY. Plasticity of Crystals (Bemerkungen zur Kristallplastizitaet), W. Boas and E. Schmid. *Mitteilungen der deutschen Materialpruefungsanstalten (Berlin)*, no. 10, 1930, pp 105-108, 2 figs.

Study of shear and slip; tensile strength and normal dilation; critical shear and elastic slip at yield point of metal crystals.

ELECTRIC FURNACES

HIGH FREQUENCY. Status of High-Frequency Furnaces Among Other Furnaces Used in Sweden for Production of Steel (Hogfrekvensugnens Plats Bland Andra I sverige anvanda ugnar for stalframstallning), C. Gejrot. *Teknisk Tidskrift (Stockholm)*, vol. 60, no. 10, Mar. 8, 1930, (Bergsvetenskap), pp. 17-23, 7 figs.

Description of high-frequency induction furnaces and results of tests; power consumption; cost of installations and operations; analysis of products. (To be continued.)

MELTING. Melting Metals Electrically. *Metallurgia (Manchester)*, vol. 1, no. 3, Jan. 1930, pp. 113-114.

Brief general notes, stressing importance of cleaner melting, uniformity of heat, and accuracy of control obtained.

RESISTANCE. Electric Resistance Industrial Furnaces, V. Paschkis. *Heat Treating and Forging*, vol. 16, no. 3, Mar. 1930, pp. 376-378 and 381, 10 figs.

Advantages of Electric Heating are attained by careful design of equipment and study of conditions; high-temperature furnaces; charging and correct arrangement of product; low-temperature equipment.

STEEL MAKING. 30-Ton Electric Steel-Melting Furnace. *Engineering (Lond.)*, vol. 79, no. 3348, Mar. 14, 1930, p. 360.

Furnace constructed by Watson's Metallurgists, Ltd., Sheffield, is operated on Greaves-Etchells system; special feature is that heat is applied both above and below bath in order to obtain even temperature throughout mass of molten metal.

FIREBRICK—TESTING

Cold Crushing Strength of Fire Brick, H. K. Mitra. *Am. Ceramic Soc.—Jl.*, vol. 13, no. 2, Feb. 1930, pp. 85-87, 9 figs.

Purpose of this investigation was to determine cold crushing strength of firebrick in three directions, flat, edge, and endwise; possible mathematical relationship between values of these crushing strengths, and best procedure for testing fire-brick.

FORGINGS, STEEL

Factors in Quality and Strength of Forgings, L. M. Jordan. *Heat Treating and Forging*, vol. 16, no. 3, Mar. 1930, pp. 328-330.

Steel-making methods are of paramount importance; fatigue phenomena discussed; character of ingot important; special varieties of steel have advantages; failure from fatigue; intermittent application of load causes fatigue failure; strain hysteresis curve.

Properties of Heavy Forged Pieces (Werkstoffeigenschaften schwerer Schmiedestuecke), M. Ulrich. *Maschinenbau (Berlin)*, vol. 9, no. 4, Feb. 20, 1930, pp. 135-136, 13 figs.

Analytic discussion of processes in structure which takes place in casting of ingot and which are of influence in judging characteristics of large forged-steel workpieces; various typical cases are illustrated.

FUELS

Comparative Costs and Value of Fuels, G. F. Klein. *Black Diamond*, vol. 84, no. 15, Apr. 12, 1930, p. 11.

Difference in fuel cost is only one of several important variables to be considered; four additional factors for oil; three others for gas; total costs are compared.

CALORIFIC VALUE. Determination of Calorific Values of Liquid and Gaseous Fuels (Etwas ueber Heizwertbestimmungen fluessiger und gasfoermiger Brennstoffe). *Waerme and Kaelte Technik (Muehlhausen)*, vol. 32, no. 5, Mar. 18, 1930, pp. 4-6.

Brief discussion of methods and their reliability, and precautions to be observed in

measuring calorific values of liquid and gaseous fuels.

COMBUSTION. Commercially Defined Combustion Efficiency, W. D. Wylde. *Cassier's Mech. Handling (Lond.)*, vol. 17, no. 1, Jan. 1930, pp. 25-26.

Comparative discussion of theoretical and actual fuel combustion efficiency; effect of varying air supplies upon fuel combustion; tables illustrating maximum percentage of carbon dioxide obtainable under various conditions.

FURNACES, ANNEALING

Foundries Use Gas for Annealing, C. B. Phillips. *Iron Age*, vol. 125, no. 9, Feb. 27, 1930, pp. 637-639 and 692, 4 figs.

Gas-fired car-bottom-type furnace, used in plant of Link Belt Co., Chicago, for annealing castings, was developed over period of years, by engineering and research staff of Surface Combustion Co., Toledo, Ohio; it has door at each end and track running through it, on which cars of castings are pushed into and through furnace; hot products of combustion are recirculated; ease in charging and unloading; cost comparisons.

Experiences with Coal-Fired Annealing Pots (Beitaege zu den Erfahrungen in kohlegeheizten Topfgluehereien), H. Staebler. *Stahl und Eisen (Duesseldorf)*, vol. 50, no. 13, Mar. 27, 1930, pp. 381-391, 15 figs.

Notes on temperature in annealing charge; time required for annealing; efficiency and costs; values given relate to wire and strip annealing ovens.

CONTINUOUS. Annealing Stampings in Automatic Furnaces, W. M. Hepburn. *Machy. (N. Y.)*, vol. 36, no. 7, Mar. 1930, pp. 530-531, 1 fig.

Continuous operation and increased output are obtained in annealing drawn sheet-metal parts in conveyor-type automatic furnace.

FURNACES, HEAT TREATING

Modern Industrial Furnaces, J. Fallon. *Metal Industry (Lond.)*, vol. 36, nos. 6, 7, 8 and 9, Feb. 7, 1930, pp. 165-167, Feb. 14, 1930, pp. 189-192, Feb. 21, 1930, pp. 213-214, Feb. 28, 1930, pp. 253-254 and 256, 20 figs.

Feb. 7: Fuels available and fuel costs; general utility furnace for annealing and reheating; operating costs of town gas. Feb. 14: Three specific problems involving use of town gas, oil, and producer gas; pulverized fuel; resistance furnaces for nitrogen hardening; tube annealing and plate-heating furnaces; sheet mill furnaces. Feb. 21: Efficiency of furnaces fired by producer gas.

GAS FIRED. Design and Operation, Gas-Fired Furnaces, C. M. Walter. *Heat Treating and Forging*, vol. 16, no. 2, Feb. 1930, pp. 240-242, 4 figs.

Accurate control of air for combustion is essential factor in efficiency of heating apparatus; thermal efficiency of furnaces; regeneration and recuperation; essentials of furnace design; furnaces employing gas seals; automatic furnaces; heat balances. See Engineering Index 1929, pp. 822-823.

OIL FIELD. Overcoming the Smoking Habit in Oil-Fired Furnaces, F. J. Gutsch. *Am. Mach.*, vol. 72, no. 10, Mar. 6, 1930, pp. 417-418, 4 figs.

Description of oil-fired furnace developed by El Paso shops of Southern Pacific Co., in which rapid heating and smoke elimination are accomplished; oil drops on to sharp blast of air, which breaks it up into small particles; as subpreheating chamber heats up, heat thoroughly vaporizes oil, resulting in almost perfect combustion.

FURNACES, INDUSTRIAL

DESIGN. Furnace Capacity (Die Feuerungsleistung), P. Rosin and R. Fehling. *V.D.I. Zeit. (Berlin)*, vol. 74, no. 13, Mar. 29, 1930, pp. 395-399, 8 figs.

Discussion of fundamental equations of furnace capacity; determination of combustion properties of coal and efficiency of furnace; reaction speed of coal; design of furnaces in accordance with our knowledge of combustion processes; outline of research problems.

HEAT LOSSES. The Loss of Heat in Cooling Water Used in Furnace Practice, W. C. Buell, Jr. *Fuels and Furnaces*, vol. 8, no. 4, Apr. 1930, pp. 517-518, 2 figs.

Discussion of heat loss in cooling water applied to furnace skid pipes, lintels, door frames, valves, and dampers.

FURNACES, MELTING

PULVERIZED COAL. Melting Iron in the Rotary Furnace (La fusion de la fonte au four rotatif), C. Bouvard. *Fonderie Moderne (Paris)*, vol. 23, Dec. 10, 1929, pp. 575-580, 3 figs.

Processes of melting iron; advantages of pulverized-coal-fired rotary furnace lie in attaining very high temperatures without oxidation of metal; securing quality of finished iron differing very little from constituents of charge; possible diminution of carbon contents due to elevated temperatures; furnace heated by pulverized coal; economy of process.

ROTARY. Melting Iron in the Rotary Furnace, C. Bouvard. *Foundry Trade Jl. (Lond.)*, vol. 42, no. 701, Jan. 23, 1930, pp. 63-64, 1 fig.

Processes of melting iron; advantages of rotary furnace lie in attaining very high temperatures without oxidation of metal; securing quality of finished iron differing very little from constituents of charge; possible diminution of carbon contents and others due to elevated temperatures; furnace heated by pulverized coal; economy of process. Translated from Fonderie Moderne, Dec. 10, 1929.

HARDNESS TESTING MACHINES

Determination of Surface Hardness and Depth of Case of Hardened Workpieces with Hardness Tester "Testor" (Bestimmung der Oberflaechenhaerte und der Einsatztiefe an gehaerteten Werkstuecken mit dem Haertepruefer "Testor"), J. H. Hessenmueller. *Werkzeugmaschine (Berlin)*, vol. 34, no. 3, Feb. 15, 1930, pp. 41-45, 5 figs.

Description of equipment which employs diamond cone or pyramid for hardness testing; test results are tabulated and given in curves.

HEAT TREATMENT

Modern Methods of Heat-Treatment. S. Whyte. *Metallurgia (Manchester)*, vol. 1, no. 3, Jan. 1930, pp. 121-122.

Developments in alloy steels have directed attention to necessity for improved methods; use of salt baths; skin-hardening variations; pack hardening; case-hardening steels; rotary furnaces; protective coatings for parts required to be left soft; nitriding process.

HEAT TREATMENT SHOPS

A Heat-Treating Job Shop Organized Along Modern Lines. F. J. Oliver, Jr. *Am. Mach.*, vol. 72, no. 9, Feb. 27, 1930, pp. 375-378, 3 figs.

Description of equipment, layout, and organization of highly successful small job shop; automatic furnace control is featured on equipment, most of which has been built to specification; metallurgical testing laboratory broadens service.

MATERIALS HANDLING. Handling Carburizing Compound Mechanically. R. K. Wilson. *Matls. Handling and Distribution*, vol. 3, no. 5, Feb. 1930, pp. 32-33, 1 fig.

New mechanical method of handling carburizing compound, which has been adopted by several heat-treating and hardening plants within past year, has resulted in increased production with material saving of labor cost; mechanical equipment consists of hoppers, screw conveyors, bucket elevator, short belt conveyor with magnetic separator driving pulley, and revolving cylinder; brief outline of carburizing plant is given.

HIGH-SPEED STEEL

ANALYSIS. Tungsten-Chromium-Vanadium Determination in High-Speed Steels (Wolfram - Chrom - Vanadinbestimmung in Schnellarbeits-Staehlen), W. Brueggemann. *Chemiker-Zeitung (Koethen)*, vol. 53, nos. 96 and 98, Nov. 30, 1929, pp. 927-928, and Dec. 7, pp. 947-948.

Methods are described for determination of tungsten, chromium and vanadium.

IRON ALLOYS

ANALYSIS. The Density of Molten Iron and Steel. Benedicks, N. Ericsson, and G. Ericson. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 1930, pp. 29-30, 2 figs.

Method of determining density is described; steel or other ferrous alloy is melted in U-tube of magnesia which stands in electric tube furnace; this molten metal pressure is applied by means of nitrogen gas on one side of U-tube and difference of level in two arms is produced, which for given pressure is exact measure of density of molten metal. Translated abstract previously indexed in Archiv fuer das Eisenhuettenwesen, Jan. 1930.

MAGNETIC PROPERTIES. Magnetism and Magnetic Materials. T. D. Yensen. *Elec. Jl.*, vol. 27, no. 4, Apr. 1930, pp. 214-218, 12 figs.

Steady improvement which electric apparatus has enjoyed from beginning of industry has been due largely to continuous improvement in magnetic materials; notes on early developments and possible improvements; iron-nickel alloys, iron-cobalt, and iron-nickel-cobalt alloys are discussed. Bibliography.

MAGNETIC PROPERTIES. Demagnetization Factor and Ideal Induction Curve of Different Test Bars (Entmagnetisierungsfaktor und ideale Induktionskurve verschiedener Probeformen), H. Lange. *Mitteilungen aus dem Kaiser-Wilhelm Institut fuer Eisenforschung zu Duesseldorf (Duesseldorf)*, vol. 11, no. 23, 1930, pp. 387-396, 10 figs.

Method for ballistic recording of ideal magnetization curve and its application to determination of demagnetization factor of different test bars; conical bar as simple test bar with practically constant demagnetization factor.

IRON CASTINGS

DEFECTS. Design of Castings (Die Konstruktion von Gussstuecken), W. Schreck. *Giesserei-Zeitung (Berlin)*, vol. 27, no. 6, Mar. 15, 1930, pp. 163-166, 6 figs.

It is shown that large proportion of wasters in castings can be traced to faulty design; suggestions for proper design and construction are given.

IRON CORROSION

Unusual Corrosion (Beobachtungen ueber anormales Rosten), F. Wilborn. *Farben-Zeitung (Berlin)*, vol. 35, no. 19, Feb. 8, 1930, p. 945, 3 figs.

Previous case of corrosion in which iron was dissolved from varnished film is paralleled by experiments with pyroxylin lacquers; it was observed that iron hydroxide was formed in lacquer film; microscopic examination of broken blisters from varnish film revealed black oxide of iron on their inner surfaces; these cases of corrosion of protected surface are presented without comment as to cause or prevention.

IRON METALLURGY

Studies of Three-Element System Iron, Carbon, and Oxygen on Basis of Measurements Made by R. Schenck (Betrachtungen ueber das Dreistoffsystem Eisen-Kohlenstoff-Sauerstoff auf Grund der Messungen von R. Schenck), E. Schell and E. H. Schultz. *Zeit fuer Anorganische und allgemeine Chemie (Leipzig)*, (Special number), vol. 188, Mar. 8, 1930, pp. 290-308, 12 figs.

Report from Dortmund Research Institute of Vereinigte Stahlwerke A.-G. on phase-rule study of gas equilibria of iron with its oxides and carbides, which indicates existence of new carbide phase.

IRON-MOLYBDENUM ALLOYS

Case-Hardening of Metals by Diffusion (Die Oberflaechenveredlung der Metalle durch Diffusion), G. Grube and F. Lieberwirth. *Zeit. fuer anorganische und allgemeine Chemie (Leipzig)*, (Special number), vol. 188, Mar. 8, 1930, pp. 274-289, 10 figs.

Fourth report from laboratories of Stuttgart Institute of Technology dealing with diffusion of molybdenum in solid iron; production of homogeneous iron-molybdenum alloys by diffusion; acid corrosion of sintered iron and molybdenum alloys.

IRON AND STEEL

CLASSIFICATION. Identification of

the Exact Nature of Ordinary Ferrous Metals and Method of Manufacture or of Working of Steels (Comment reconnaitre la nature exacte des metaux ferraux courants). Raucher. *Arts and Métiers (Paris)*, vol. 82, no. 109, Oct. 1929, pp. 397-391, 12 figs.

Brief review of different kinds of irons and steels and of characteristics by which they can be identified.

OXYGEN DETERMINATION. Determination of Gases in Metals, Especially Oxygen in Iron and Steel, According to Hot-Extraction Process (Zur Bestimmung der Gase in Metallen, besonders des Sauerstoffs in Eisen und Stahl, nach dem Heissextraktionsverfahren), H. Diergarten. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 9, Mar. 1930, pp. 577-586, 12 figs.

Application of process; oxygen segregation; oxygen analysis and metallographic observations; critical discussion of process. See Engineering Index 1929, p. 1017, for reference to first part of paper.

PROTECTIVE COATINGS. The Rust-Proofing of Iron and Steel Products, C. H. Proctor. *Metal Cleaning and Finishing*, vol. 2, no. 3, Mar. 1930, pp. 215-218 and 231.

Discussion of white and black rust-proof coatings and their advantages; solution formulas and operating details for producing protective coatings on iron and steel products.

LOCOMOTIVES—DROP FORGING

Large and Unusual Drop Forgings. *Iron Age*, vol. 125, no. 14, Apr. 3, 1930, pp. 1005-1007, 5 figs.

Methods of manufacturing large drop forgings placed on locomotives, as substitutes for steel castings and machined hammer or press work at Baldwin Locomotive Works, Eddystone, Pa.; economical production in small numbers; die blocks have relatively small production; roughing frequently done on anvil; long pieces drop forged at ends.

MALLEABLE IRON CASTINGS

Choice of Raw Materials for Malleable Cast Iron, J. V. Murray. *Metallurgia (Manchester)*, vol. 1, nos. 3 and 4, Jan. 1930, pp. 107-109, Feb., pp. 161-162 and 165, 10 figs.

Jan.: Selection of malleable pig iron will depend upon method of melting, size and section of castings, chemical composition, fracture and scientific control of melt; characteristics of pig iron; annealing ore and other packing material; fuels and minor materials are briefly discussed. Feb.: Effect of carbon, graphitic carbon, combined carbon, silicon, sulphur, manganese, and of phosphorus. Bibliography. (To be continued.)

High-Test Cupola Malleable Cast Iron Melted with Hematite (Hochwertiger, mit Haematit erschmolzener Kupolofen Temperguss), O. Brauer. *Zeit. fuer die Gesamte Giessereipraxis (Berlin)*, vol. 51, no. 4, Jan. 26, 1930, pp. 70-72, 4 figs.

Exception is taken to article by Stotz in Jan. 19, issue of this journal in which he states that hematite has injurious effect on malleable iron; reply of Stotz is appended.

SPECIFICATIONS. New DIN 1692 Standard Specification for Malleable Cast Iron (Das neue Normblatt fuer Temperguss, DIN 1692), R. Stotz. *Giesserei (Duesseldorf)*, vol. 17, no. 11, Mar. 14, 1930, pp. 251-253, 4 figs.

Specifications for quality classifications; standard tensile test bars; comparison with specifications of other countries; standards for malleable castings.

MALLEABLIZING

Theory of Malleablizing Process, N. G. Hirschovich and E. K. Vidden. *Trudi Instituta Metallov—Bul. (Moscow)*, no. 4, 1929, 119 pp., 49 figs.

First of series of researches on properties of malleable cast iron; review of literature on malleablizing process; mechanism of graphitization and decarburization of white cast iron; growth of malleable iron upon annealing. (In Russian, with abstract in English.)

METALS

DEFORMATION. Problem of Plasticity—Deformation at Low Temperature (Zur Frage der Plastizitaet. Verformung bei tiefen Temperaturen), M. Polanyi and E. Schmid. *Mitteilungen der deutschen Materialpruefungsanstalten (Berlin)*, no. 10, 1930, pp. 101-104, 5 figs.

Study of different forms of plasticity; elastic limit of zinc and cadmium crystals at low temperatures; deformation at minimum temperatures.

EUTECTICS. The Composition of Eutectics, D. Stockdale. *Inst. of Metals—Advance Paper*, no. 526, for mtg., Mar. 12-13, 1930, 19 pp., 9 figs.

Author has held view for some time that in binary eutectic, atoms of two elements are present simple ratio; experimental work described was undertaken to get evidence for or against this view; although this object has not been attained, results in themselves are of interest; eutectic systems examined were aluminum-copper, antimony-silver, cadmium-tin, cadmium-zinc, copper-silver, and lead-tin.

HISTORY. The Early Use of the Metals, T. A. Rickard. *Inst. of Metals—Advance Paper*, no. 525, for mtg. Mar. 12-13, 1930, 43 pp.

World survey is given of early history of metals, and particularly of non-ferrous metals; melting of copper probably preceded its extraction from minerals by some centuries and production of bronze or hardened copper was later stage in metal culture; first melting of metal out of stone appears to have occurred about 3500 B. C.; metal articles fashioned at earlier periods were made from native gold, silver, or copper, or from meteoric iron. Bibliography.

RECRYSTALLIZATION. Recent Studies of Recrystallization of Metals (Neuere Untersuchungen ueber die Rekistallisation der Metalle), J. Weerts. *V. D. I. Zeit. (Berlin)*, vol. 74, no. 13, Mar. 29, 1930, pp. 400-402, 2 figs.

Review of research work done at Kaiser Wilhelm-Institut fuer Metallforschung and abstract of papers by A. E. van Arkel, U. Dehliner, and G. Tammann, read at Jan. 23, 1930, meeting of Deutsche Gesellschaft fuer Metallkunde; effect of low-temperature annealing; laws of recrystallization; coarse re-

crystallization; recrystallization nuclei; atomistic principles of recrystallization.

RECRYSTALLIZATION. Kinetics of Recrystallization (Zur Kinetik der Rekristallisation), R. Karnop and G. Sachs. *Zeit. fuer Physik (Berlin)*, vol. 60, nos. 7/8, Feb. 26, 1930, pp. 464-480, 10 figs.

Report from Kaiser Wilhelm-Institut fuer Metallforschung in Berlin-Dahlem on experimental study of recrystallization of conical copper rods, at various temperatures; determination of crystal growth in recrystallizing aluminum; time relations of nucleus formation and speed of growth of crystals.

RECRYSTALLIZATION. Recrystallization of Metals (Zur Rekristallisation der Metalle), G. Tammann and W. Crone. *Zeit. fuer anorganische und Allgemeine Chemie (Leipzig)*, vol. 187, no. 4, Mar. 7, 1930, pp. 289-312, 13 figs.

Report from Department of Physical Chemistry of University of Goettingen; variations in texture of castings particularly in their central portions; variations in grain size of recrystallized metals; isothermal grain growth in primary and secondary recrystallization; softening of wire and change in structure after very short heat treatment; effect of cooling rate on primary recrystallization; recrystallization in small plates.

SOLIDIFICATION. The Cooling and Solidification of Metals, A. Campion. *Foundry Trade Jl. (Lond.)*, vol. 42, no. 702, Jan. 30, 1930, pp. 88-89.

Apart from mold of local chilling, rate of cooling can to certain extent be controlled by temperature of metal at time of casting; with exception of steel and cast iron very little reliable data is available regarding change of volume of metals in liquid state; as aid to control of cooling directionally manner in which flow of heat takes place is considered; heat conducted into mold from one cooling surface will retard cooling of adjacent surface; discussion given.

METALS ANALYSIS

Rolling and Recrystallization Texture of Face-Centered Metals (Walz und Rekristallisationstextur regular - flaechenzentrierter Metalle), v. Goeler and G. Sachs. *Mitteilungen der deutschen Materialpruefungsanstalten (Berlin)*, no. 10, 1930, pp. 90-101, 55 figs.

Results of tests and analyses, forming parts III, IV, and V of series of investigations on texture and properties of rolled and recrystallized metals.

SPECTROGRAPHIC. Spectroscopic Analysis of Metals, D. M. Smith. *Brit. Non-Ferrous Metals Research Assn.—Bul.*, no. 28, Mar. 1930, pp. 7-14, 4 supp. plates.

Description of results obtainable by use of spectrographic methods preceded by brief discussion of production of spectrum of metal and its chief characteristics; in case of spectrographic assay degree of accuracy can be considerably improved by accumulation of wider range of standard samples for comparison; recent developments.

METALS CORROSION

Hypochlorite Corrosion is Cut by Addition of Salts and Bases, G. N. Quam. *Food Industries*, vol. 2, no. 3, Mar. 1930, pp. 121-122.

Discussion of investigations conducted to determine corrosion of metals and alloys by chemical sterilizers such as sodium hypochlorite; tables giving average loss in milligrams per sq. in. of samples in sodium hypochlorite.

Influence of Cylic Stresses on Corrosion, D. J. McAdam, Jr. *Am. Inst. of Min. and Met. Engrs.—Tech. Pub.*, no. 329, Feb. 1930, 42 pp., 17 figs.

Paper discusses influence of cyclic stress on corrosion of carbon and ordinary alloy steels, corrosion-resisting steels, monel metal and aluminum alloys; damage due to corrosion is estimated by comparing fatigue limit of previously corroded specimen with endurance limit of metal; lowering of fatigue limit represents damage caused by corrosion, either with or without cyclic stress; results are expressed in diagram. Bibliography.

New Principles of Metal-Corrosion Research (Neuere Grundlagen der Metallkorrosionsforschung), F. Mueller. *Zeit. fuer Angewandte Chemie (Berlin)*, vol. 43, no. 11, Mar. 15, 1930, pp. 225-229, 1 fig.

Review of chemical theories of metal corrosion since time of Lavoisier; enumeration of protective measures. Bibliography.

METALS FATIGUE

A Study of the Ikeda Short-Time (Electrical Resistance) Test for Fatigue Strength of Metals, H. F. Moore and S. Konzo. *Univ. of Ill.—Eng. Experiment Station—Bul.*, no. 205, vol. 27, no. 33, April 15, 1930, 34 pp., 19 figs.

Ikeda electrical resistance method for determining endurance limit under repeated stress was investigated in connection with reversed-flexure fatigue tests of Armco iron, 0.20 carbon steel, 0.52 carbon steel, hardened tool steel, brass, monel metal, and copper; conclusions are enumerated.

METALS RESEARCH

Mitteilungen der Deutschen Materialpruefungsanstalten; Sonderheft 10. *Berlin*, Julius Springer, 1930, 142 pp., illus., and diagrams., 23 r.m.

Researches collected in this volume treat of numerous matters of interest to student of metals; influence of temperature and conditions of cooling on cast zinc, structure of cast metals and alloys, wire-rope testing, deformation of metals at low temperatures, researches on metallic crystals, etc., are among subjects; investigations were made at Kaiser-Wilhelm Institut fuer Metallforschung und Staatliche Materialspruefungsamt. Eng. Soc. Lib., N. Y.

METALS TESTING

CREEP. Creep Stress Determination, W. Rohn. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 1930, pp. 22-23, 2 figs.

Author propounds novel method of making creep tests; he bases his ideas on fact that creep limit varies rapidly with temperature so that it would be more satisfactory to determine limiting creep temperature for given stress than creep stress for given temperature; method should prove of very great value, especially where approximate guide to creep properties of material is required. Abstract translated from German.

ENDURANCE. Endurance Testing Ma-

chine for Alternating Torsional Load (Dauerpruefmaschine fuer Torsionswechselbelastung), W. Spaeth. *Werkzeugmaschine (Berlin)*, vol. 34, no. 3. Feb. 15, 1930, pp. 45-49, 3 figs.

Description of equipment of Losenhausenwerk Duesseldorf, employing, swinging motor for drive, which allows for quick and exact execution of various tests.

STRESSES. Stresses Due to Forging and Heat Treatment (Schmiedespannungen, Verguetungsspannungen und Waermespannungen), G. Sachs. *Mitteilungen der deutschen Materialpruefungsanstalten (Berlin)*, no. 10, 1930, pp. 43-48, 22 figs.

Methods of testing to determine effect of treatment on metals, such as forging, hardening, annealing, quenching, etc.; results of tests to determine stresses in round bars of steel at 0:55 deg. cent.; comparison of effect of different treatments.

TEMPER. The Pile Temper Testing Machine, R. G. Johnston. *Metal Industry (Lond.)*, vol. 36, no. 11, Mar. 14, 1930, pp. 293-296, 4 figs.

Explanation of construction and operation of machine for testing temper of metals and alloys; analysis of results obtained.

WEAR. Theory of Wear (Ueber die Abnutzungtheorie), H. Friedrich. *Maschinenbau (Berlin)*, vol. 9, no. 4, Feb. 20, 1930, pp. 129-131, 4 figs.

Comparison is made between abrasion by friction and by machinery; e.e. grinding, filing, sawing, etc., in order to find explanation for theory of wear; experiments on abrasion-testing machine; comparison of calculated and measured values.

METALLURGY

RESEARCH. Metallurgical Research from the Chemical Point of View, H. W. Gillett. *Indus. and Eng. Chem.*, vol. 22, no. 3, Mar. 1930, pp. 232-240, 6 figs.

Importance of metallurgical research and relation of metallurgy to chemistry; trend toward centralization of research; importance of proper training of research men; classification and functions of institutions fostering research; cooperative research movement; utilization of research facilities by industry; metallurgical research in Europe.

MOLYBDENUM STEEL

Calcium Molybdate, Iron and Steel Making, T. W. Hardy. *Blast Furnace and Steel Plant*, vol. 18, no. 4, Apr. 1930, pp. 613-617, 1 fig.

Reasons why cost of molybdenum steel is not excessive; history of use of molybdenum; occurrence of molybdenum in nature; uses of molybdenum; early application of molybdenum to ferrous metallurgy; effect of molybdenum on properties of steel; development of calcium molybdate process; characteristics of calcium molybdate. (To be concluded.)

NICKEL

AGE HARDENING. Aging of Cold-Worked Metals (Sur le vieillissement des métaux écrouis), J. Galibourg. *Académie des Sciences—Comptes Rendus (Paris)*, vol. 190, no. 3, Jan. 20, 1930, pp. 168-170, 1 fig.

Comparison between mechanical properties of nickel bars annealed in hydrogen and aged at 15 deg., 175-180 and 225-235 deg. may be used to demonstrate aging effect produced at high temperatures; effect is less marked than for steels; curves are given showing effect of successive heat treatments for 30 min. and 1 hr. at 220-230 deg.

NICKEL ALLOYS

CASTINGS. Nickel Casting Alloys, J. McNeil. *Metal Industry (Lond.)*, vol. 36, no. 10, Mar. 7, 1930, pp. 275-278.

Physical properties of nickel brasses and nickel silvers are considered; founding; uses; nickel high-tensile brasses; nickel bronzes; high nickel-copper alloys; founding; nickel-chromium and nickel-chromium-iron alloys. (To be concluded.) Paper presented before Co-ordinating Committee at Birmingham.

NICKEL STEEL

PHYSICAL PROPERTIES. The Thermal and Elastic Properties of Elinvar: A Study of an Elinvar Spring in the Galitzin Vertical Seismograph at Kew Observatory, F. J. Scrase. *Jl. of Sci. Instruments (Lond.)*, vol. 6, no. 12, Dec. 1929, pp. 385-392, 3 figs.

In order to overcome disadvantage, elinvar spring was recently fitted to vertical seismograph at Kew Observatory; after loading spring, "creep" remained appreciable for several months; moreover rate of creep was dependent on temperature after making due allowance for these effects it was found that temperature coefficient of elastic constant of elinvar spring was about one-tenth of that of steel spring.

NITRIDATION

Nitrogen Hardening. *Metallurgist (Supp. to Engineer, Lond.)*, Mar. 1930, pp. 33-34.

While process is making considerable amount of headway this seems to be restricted by some features of process and its product as they now stand; advantages are ideal conditions from point of view of industrial production, but they are offset to certain extent by fact that process itself is relatively very lengthy; nitrogen-hardened limited to uses where hardened article is not exposed to any violent shock; possible lines of future development in nitrogen-hardening process are briefly indicated.

NON-FERROUS METALS, LIGHT

Light Alloys in Engineering, S. Whyte. *Metallurgia (Manchester)*, vol. 1, no. 2, Dec. 1929, pp. 59-60 and 64.

Aluminum and magnesium form basis of light-alloy industry; developments have perfected properties of these alloys and they are now extensively used on economic basis; compositions of best-known alloys have not so wide application as aluminum, but are rapidly coming into favor; treatments to protect against corrosion.

PIPE, CAST IRON

CORROSION. Galvanic Corrosion on Cast-Iron Pipes, R. J. Kuhn. *Indus. and Eng. Chem.*, vol. 22, no. 4, Apr. 1930, pp. 335-341, 7 figs.

Cast-iron pipes that have been buried in soils in vicinity of New Orleans are susceptible to type of corrosion due to electrolytic

currents; study has been made to determine source of these currents; current densities of discharge at surface of pits have been determined both by method used at Bureau of Standards and by potential tangent method; by this method current density at surface of pits is found to be 54.8 milliamperes per sq. ft.

PIPE, WELDED STEEL

TESTING. Physical Properties of Electrically Welded Steel Tubing, H. L. Whittemore, J. S. Adelson and E. O. Seaquist. *U. S. Bur. of Standards—Jl. of Research*, vol. 4, no. 4, Apr. 1930, pp. 475-500, 25 figs.

Report on tests of longitudinally welded sheet-steel tubing, 5/8 to 3 in. in diam.; welds were submitted to hydrostatic test, tensile test of welds in circumferential strips, torsion test, and axial crushing test; generally properties of base metal can be used in determining working stresses, no allowance being necessary for altered structure in and adjacent to weld.

PRESSURE VESSELS

ELECTRIC WELDING. Arc Welding at a Large Boiler Works. *Engineer (Lond.)*, vol. 149, no. 3872, Mar. 28, 1930, pp. 344-345, 6 figs.

Particulars of English Electric welding installation in Thompson Bros. tank shops at Bilston; examples are given of welding chemical vessel tested to pressure of 1500 lb. per sq. in.; and welded rotary drier; installation is composed of 12 welding sets, each consisting of 10-hp. squirrel-cage induction motor coupled to steel-frame welding generator capable of giving from 250 to 300 amperes at 30 volts.

PROTECTIVE COATINGS

METALLIC. "Alumetier" Process of Coating Iron and Steel (Die Alumetierung von Eisen and Stahl). *Zeit. fuer die Gesamte Giessereipraxis (Berlin)*, vol. 51, no. 2, Jan. 12, 1930, pp. 9-10.

Method described is an especially developed metal-spraying process, by which material is first sprayed with aluminum layer, then covered with airtight substance and finally heated at high temperature; mention is also made of so-called "fervalizing," which differs from first process in that to aluminum layer is added coating of other metals, in order to prevent oxidation of aluminium.

RAILS, MANGANESE STEEL

Why Do Intermediate Manganese Steel Rails Fail? H. H. Morran and J. R. Mooney. *Ry. Age*, vol. 88, no. 10, Mar. 8, 1930, pp. 595-598, 6 figs.

Discussion of investigation of head failures of rails undertaken by R. W. Hunt Company; table giving chemical analysis of new and failed rails; table of physical characteristics of six of specimens tested.

REFRACTORY MATERIALS

Refractory Materials, C. Presswood. *Metallurgia (Manchester)*, vol. 1, nos. 1, 2, and 3, Nov. 1929, pp. 15-16, Dec. 1929, pp. 81-82, and Jan. 1930, pp. 127-128, 3 figs.

Nov.: Importance of refractories in metallurgy; general principles governing their selection and use; furnace linings constitute serious item in production costs; properties of refractory materials in general. Dec.: Examination of refractories in laboratory; chemical analysis; physical tests; Seger cone test; atmospheric influence; under-load test. Jan.: Expansion tests; mechanical strength; resistance to abrasion.

TESTING. Tests and Specifications for Refractory Materials in North America (Pruefverfahren und Guetenormen fuer feuerfeste Erzeugnisse in Nordamerika), W. steger. *Tonindustrie-Zeitung (Berlin)*, vol. 53, nos. 93, 98, 100, 102-103 and 104, Nov. 21, 1929, pp. 1638-1640, Dec. 9, pp. 1722-1724, Dec. 16, pp. 1753-1755, Dec. 23, pp. 1786-1790, and Dec. 30, pp. 1812-1814, 6 figs.

Nov. 21: Testing for pyrometric equivalent. Dec. 9: Test for porosity and permanent volume changes. Dec. 16: Resistance of fireclay brick to thermal spalling. Dec. 23: Clay firebrick for stationary boilers. Dec. 30: Specifications for plastic fireclay refractories.

SCRAP METAL

Scrap Institute Adds to Program. *Iron Age*, vol. 125, no. 11, Mar. 13, 1930, pp. 797-798.

Account of meeting in Chicago of Institute of Scrap Iron and Steel; resolution was adopted expressing disapproval of any departure from open competitive bidding and fair awards in marketing of scrap produced by railroads; specifications for scrap sorting; mergers in industry are urged; code violations considered.

SHEET METAL

TESTING. Dilatation of Sheets (Die Dehnung von Blechen), G. Sachs and W. Stenzel. *Mitteilungen der deutschen Materialpruefungsanstalten (Berlin)*, no. 10, 1930, pp. 58-68, 21 figs.

Results of tests on sheet-metal bars of 5.0, 2.0, and 0.5 mm. thickness; tensile tests with bronze bars; influence of fracture; practical significance of results.

SHEET MILLS, CONTINUOUS

Straight-Line Making of Sheets. T. H. Gerkin. *Iron Age*, vol. 125, no. 15, Apr. 10, 1930, pp. 1064-1065, 2 figs.

Layout of sheet mill of Newton Steel Co., Monroe, Mich., which utilizes mechanical handling devices for continuous production of sheets.

SHEET STEEL TESTING

Hardness Tests of Steel Sheets Aid Production Results, W. H. Graves. *Iron Trade Rev.*, vol. 86, no. 13, Mar. 27, 1930, pp. 59-60.

Suggested method for specifying steel sheets of drawing quality; it has been found that laboratory investigation of drawing qualities of automobile body stock is more accurate than press-room operation.

SHIPS

PROTECTIVE COATINGS. Effect of Seawater on Paint (Einfluesse des See-

wassers auf Anstriche), Baerenfaenger. *V. D. I. Zeit. (Berlin)*, vol. 74, no. 12, Mar. 22, 1930, pp. 373-374, 11 figs. partly on supp. plate.

Director of chemical engineering laboratory of City of Kiel reports observations on corrosion of ship bottoms due to rusting and to tuberculation; review of measures proposed for protection of ship bottoms against corrosion by means of various paints and coatings.

STAINLESS STEEL

Acid-Resisting Steels, W. H. Hatfield. *Metallurgia (Manchester)*, vol. 1, no. 1, Nov. 1929, pp. 17-20.

Comparison of resistance of ordinary mild steel, 14 per cent chromium steel, and some chromium-nickel steels of variable chromium and nickel contents; tabular analysis and results of corrosion tests with nitric, phosphoric, sulphuric, and hydrochloric acids. Bibliography.

Corrosion-Resisting Steels and Their Applications, J. H. G. Monypenny. *Iron and Steel Industry (Lond.)*, vol. 3, no. 5, Feb. 1930, pp. 149-154, 12 figs.

Influence of workshop processes on mechanical properties and corrosion resistance. (Continuation of serial.)

MACHINING. Machining Stainless Steel, J. H. Barber. *Metallurgia (Manchester)*, vol. 1, no. 2, Dec. 1929, pp. 75-77, 2 figs.

Essentials for satisfactory machining are rigidity of job, rigidity of machine tool, rigidity of cutting tool, and use of suitable cutting tool, which must be good high-speed steel; turning, drilling, milling, sawing, filing, and tapping are discussed.

STEEL

TEMPERATURE EFFECT. The Strength of Steel at High Temperature, L. M. Jordan. *Heat Treating and Forging*, vol. 16, no. 2, Feb. 1930, pp. 182-184.

Review of recent investigations into behavior of steel under stress when subjected continuously to high temperatures.

TEMPERATURE EFFECT. Creep of Steel Under Simple and Compound Stresses, R. W. Bailey. *Engineering (Lond.)*, vol. 129, nos. 3345 and 3347, Feb. 21, 1930, pp. 265-266, and Mar. 7, pp. 327-329, 15 figs.

Two series of tests are recorded; one was made upon steel tubes strained separately at same temperature by tension and torsion producing equal maximum shear stress; other was made upon lead pipes under internal pressure with superimposed axial loading. Paper read before World Power Conference, Tokio.

STEEL CASTINGS

HEAT TREATMENT. Continuous Equipment for Heat-Treating Steel Castings, A. C. Jones. *Fuels and Furnaces*, vol. 8, no. 4, Apr. 1930, pp. 475-478, 4 figs.

Two continuous, oil-fired, pusher-type furnaces used in heat-treating steel castings; heat to 1650 deg. fahr., quench in air and draw at 1225 deg. fahr.

STEEL HEAT TREATMENT PLANTS

A Modern Commercial Heat Treating Plant. *Heat Treating and Forging*, vol. 16, no. 3, Mar. 1930, pp. 331-335, 12 figs.

New plant of Sindling Steel Treating Co., Chicago, is described; routing and safeguarding operations; tool department; nitriding department; cyaniding, sand blasting, tumbling, lead baths; inspection department; materials-handling efficiency.

STEEL INGOTS

SEGREGATION. Crystallization and Segregation Phenomena in 1.10 Carbon-Steel Ingots (Kristallisations och segringsfenomen i 1-10 kolstaelsgoet), A. Hultgren. *Jernkontorets Annaler (Stockholm)*, vol. 85, no. 3, 1930, pp. 95-155 and (discussion) 155-158, 83 figs. partly on supp. plates.

Report of experiments and investigations at Springfield plant, steel is melted in eleccent carbon steel, 0.20 per cent Si, 0.30 per cent Mn, 0.013 per cent P, and 0.009 per cent S; supplement discusses preparation and etching of ingot sections.

STEEL MANUFACTURE

Common Errors in Steel-Making, W. Lister. *Metallurgia (Manchester)*, vol. 1, nos. 2, 3, and 4, Dec. 1929, pp. 79-80, Jan. 1930, pp. 103-104 and Feb. 1930, pp. 158-160 and 165, 7 figs.

Dec.: Charging and melting; acid cold charge; basic cold charge; when second charge is necessary. Jan.: Working down; acid charge; basic cold, hot, and electric charge. Feb.: Mold stock; pit casting; steel molds; care of molds. (To be continued.)

Modern Developments in Plant for the Manipulation of Steel, T. W. Hand. *Metallurgia (Manchester)*, vol. 1, no. 4, Feb. 1930, pp. 137-142.

Vital importance of mechanical equipment to progressive development in use of iron and steel; comparison of British and American practice. Extract from paper read before Sheffield Soc. of Engrs. and Metallurgists.

BASIC. Investigation into the Course of Manganese and Phosphorus Reactions in the Basic Steel-Manufacture Process (Untersuchungen ueber den Verlauf der Mangan und Phosphorreaktionen bei den gasischen Eisenherstellungsverfahren), H. Schenck. *Kruppsche Monatshefte (Essen)*, vol. 11, nos. 1 and 2-3, Jan. 1930, pp. 1-23 and Feb.-Mar. 1930, pp. 29-38, 7 figs.

Author discusses question whether chemical equilibrium in bath and slag is reached in time available; describes procedure for making tests on metal from open-hearth furnaces and from Bessemer converters; conditions for equilibrium in manganese reactions and in phosphorus reactions and laws governing equilibrium in these reactions.

BESSEMER PROCESS. The Case for Bessemer Steel. *Engineering (Lond.)*, vol. 129, no. 3350, Mar. 28, 1930, pp. 413-414.

Whatever the reason for gradual abandonment of converter in United Kingdom, view that bessemer process is obsolete and generally unsatisfactory is not shared by rival metallurgical firms in foreign countries; iron ore high in phosphorus, suitable for manufacture of phosphoric pig demanded by basic bessemer process, is to be found in various parts of Great Britain, and it is believed

that given suitable organization, basic bessemer steel could be made in Great Britain and sold at figure comparing favorably with price of Continental material.

DUPLEX PROCESS. Practice in Making Duplex Steel, J. E. Carlin. *Iron Age*, vol. 125, no. 13, Mar. 27, 1930, pp. 925-927.

Duplex steel practice is carried out usually in tilting Talbot furnace of 100 to 300 tons capacity; certain refinements have been developed recently and process is now capable of producing steel of any carbon content of quality which rivals that of regular basic open-hearth process; characteristics of slag; proportioning charge.

MUSSO PROCESS. The Musso Steel Process, C. E. Parsons. *Can. Min. Jl. (Gardenvale, Que.)*, vol. 51, no. 11, Mar. 14, 1930, pp. 242-245, 2 figs.

Musso process provides for manufacture of steel ingots by production of sponge iron, with melting in suitable furnaces for purification of sponge iron and its conversion to steel; description of process; features of construction; chemical reactions; concentrating and melting iron; pilot plant, with capacity of about 4 tons of steel ingots per day, is now under construction in Ottawa.

RESEARCH. The Physical Chemistry of Steel-Making: Deoxidation with Silicon in the Basic Open-Hearth Process, C. H. Herty, Jr., C. F. Christopher and R. W. Stewart. *Min. and Met. Investigations—Cooperative Bul.*, no. 38, 1930, 172 pp., 33 figs.

Why deoxidation is necessary; oxygen in steel; functions of deoxidizer; method of studying deoxidation with silicon; determination of non-metallic content of steel by inclusion-count method; log sheets, tabular data and graphs on results obtained on all heats studied; discussion of results and enumeration of conclusions drawn as result of experiments, carried out on 40, 90, and 250-ton furnaces. Bibliography.

STEEL METALLOGRAPHY

A Heuristic Theory of the Structure of Steel, L. Cammen. *Am. Soc. Steel Treating—Trans.*, vol. 17, no. 4, Apr. 1930, pp. 563-569.

According to new theory steel consists, not of aggregation of crystals with amorphous cement in between, but of matrix of extremely fine crystalline matter (so fine that even most powerful microscope does not disclose its structure), in which are embedded now visible crystals of same presumable composition as matrix material; theory is said to explain why, at room temperature, steel breaks through crystals and not through cement.

TENSILE. Tensile Properties of Rail and Some Other Steels at Elevated Temperature, J. R. Freeman and G. W. Quick. *U. S. Bur. of Standards—Jl. of Research*, vol. 4, no. 4, Apr. 1930, pp. 549-591, 38 figs.

Study of ductility of steels in temperature range 400 to 700 deg. cent. showed marked decrease in elongation and reduction of area values, termed "secondary brittleness"; temperature gradients in rail during cooling in air and when quenched in water; shatter cracks and cracks may be due to stresses developed while cooling through secondary brittle range.

STRIP MILLS

Completes Third Hot Strip Mill, J. B. Pletcher. *Iron Trade Rev.*, vol. 86, no. 12, Mar. 20, 1930, p. 41, 1 fig.

Description of new continuous unit of Acme Steel Co., Riverdale, Ill., which is geared to produce 12,000 tons monthly in narrow widths and thin gages; hot strip widths of 3/4 to 6 in. are provided by unit, and gages down to 0.025 in. are being rolled.

Strip Mill Provides Flexibility, R. A. Fiske. *Iron Age*, vol. 125, no. 12, Mar. 20, 1930, pp. 846-850, 6 figs.

Foremost among features of new No. 3 hot strip mill at Riverdale, Ill., plant of Acme Steel Co., is use of two-high stands equipped with rolls that are true cylinders; instead of rolls having necks, roller bearings back up rolls on extensions of rolling surface.

TOOL STEEL HARDENING

Internal Phenomena Occurring with Hardening and the Hardening of Tool Steel (Die inneren Vorgaenge beim Haerten von Arbeitsstaehlen), J. Maerck. *Bergbau*, vol. 42, nos. 43 and 44, Oct. 24, pp. 607-610, and Oct. 31, pp. 620-623, 7 figs.

Heating and cooling curves are presented; diagram of state and solidification diagram; iron-cementite diagram; hardening diagram; hardening defects; quenching and quenching defects; annealing; application to rock drills.

TOOL STEEL QUENCHING

On the Cause of Quenching Deformation in Tool Steels, D. Hatori. *Tohoku Imperial Univ.—Sci. Reports*, vol. 18, no. 5, Dec. 1929, pp. 665-698, 34 figs.

Results of experiments on deformation produced by quenching prisms and cylinders of various lengths or sections, made of carbon steel, special tool steel, or high-speed steel; cause of this deformation is discussed, comparing it with that of Armco iron; warping is also caused by quenching; deformation and warping are produced by difference of structural change and of thermal expansion at different portions of specimens. (In English.)

TUBES

COLD WORKING. Study of Cold-Worked, Thick-Walled Tubes with Special Regard to Changes in Properties of Materials (Untersuchungen an kaltgereckten, dickwandigen Rohren, unter besonderer Beruecksichtigung der Veraenderungen der Werkstoffeigenschaften), H. Klein. *Mitteilungen aus dem Wilhelm-Institut fuer Eisenforschung (Duesseldorf)*, vol. 11, no. 20, 1929, pp. 331-341, 13 figs.

Theory of thick-walled hollow cylinders; calculation of stresses in such cylinders for elastic failure of materials; tests were carried out on specimen tubes of nickel-chromium and nickel-tungsten steel and of unalloyed steel.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,751,482, March 25, 1930, Core and Process of Forming the Same, Emil L. Leasman, of Milwaukee, Wisconsin.

This patent relates to a binder for producing foundry cores as a substitute for the usual organic binder which, when produced, avoids the usual fumes and undesirable smoke. Such a binder preferably consists of sodium phosphate suspended in water.

1,751,500, March 25, 1930, Method of Forming Articles from Heat-Treatable Aluminum-Base Alloys, William C. Winter, of Parnassus, Pennsylvania, Assignor to Aluminum Company of America, of Pittsburgh, a corporation of Pennsylvania.

This invention relates to the forming of sheet metal articles from aluminum-base alloys which includes heating the alloy sheet to cause an increased solution of excess copper before die-pressing it to increase the hardness and tensile strength. A very substantial increase in certain of the physical properties is claimed by heating the sheet to increase the solution of the soluble constituent of the alloy.

1,752,490, April 1, 1930, Process for Changing the Properties of Silicon Steel, John Clarence Karcher, of Montclair, New Jersey, Assignor to Western Electric Company, Incorporated, of New York, N. Y., a corporation of New York.

This invention relates to a process for changing the properties of silicon steel and it particularly describes the process of heating the silicon steel to a high temperature and cooling quickly to a medium temperature at a rate of approximately 10 degrees Cent. per minute and then cooling the steel slower than a water quench, but faster than quenching in open air.

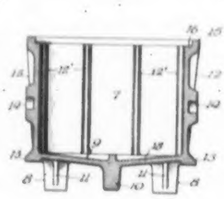
1,753,161, April 1, 1930, Pen-Point Alloy; 1,753,162, April 1, 1930, Alloy, John E. Woodward of New York, N. Y., Assignor to Kastenhuber & Lehrfeld, of New York, N. Y., a Partnership of Charles F. Kastenhuber, William F. Lehrfeld, and Hugo R. Lehrfeld.

These patents relate to an alloy, particularly for use in pen-points, comprising nickel, tungsten and a subsequent treatment with osmium. This is brought about by dissolving the tungsten in nickel and a final treatment with osmium by the pen manufacturer. The alloy comprises approximately 80 per cent of osmium, 10 per cent of platinum and 10 per cent of a base alloy, comprising 75 parts of tungsten to 25 parts of nickel.

1,754,372; 1,754,373; 1,754,374, April 15, 1930, Annealing Pot, Robert S. Stewart, of Chicago, Illinois, Assignor to The American Brake Shoe & Foundry Company, of New York, N. Y., a corporation of Delaware.

1,754,423, April 15, 1930, Annealing Pot, Michael W. Gleisner, of Racine, Wisconsin, Assignor to The American Brake Shoe & Foundry Company, of New York, N. Y., a corporation of Delaware.

These patents all relate to improved annealing pots and, as particularly described in patent No. 1,754,372, and as shown in the figure here-



inafter reproduced, the pots are provided with integral legs 8 and 10 to support and space the pots in a stack and with recessed trunnions 14 for convenient handling. This particular construction eliminates numerous parts, decreasing the overall height, decreasing the quantity of pot metal to be heated and increasing the fuel economy.

1,755,554, April 22, 1930, Heat-Treated Nickel-Copper-Aluminum Alloy and Method of Heat Treating the Same;

1,755,555, April 22, 1930, Manufacture of Alloys of Copper, Nickel and Aluminum;

1,755,556, April 22, 1930, Heat-Treated Copper-Nickel-Aluminum Alloy;

1,755,557, April 22, 1930, Copper-Nickel-Aluminum Alloy and Method of Heat Treating the Same, William A. Mudge, of Huntington, West Virginia, Assignor, by mesne Assignments, to The International Nickel Company, Inc., of New York, N. Y., a corporation of Delaware.

These patents relate to nickel-copper-aluminum alloys and particularly to a heat treatment to increase the physical properties and consists in subjecting the material to a temperature of approximately 1000 degrees and cooling slowly. It is pointed out that the supposition that the alloys of approximately 20 per cent aluminum were considered true solid solutions and that normally the heat treatment would not cause the noted results is fallacious. The present theory is that these alloys are not true solid solutions and that heat treatment between 600 degrees Fahr. and 1200 degrees Fahr. will cause considerable variation in the physical properties.

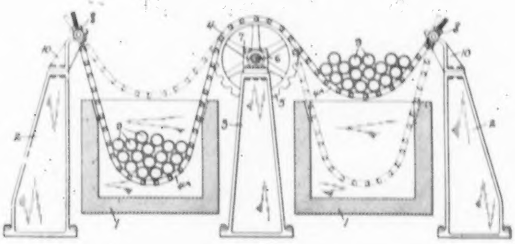
1,755,391, April 22, 1930, Process of Producing a Phosphate Coating on Metal, Matthew Green and Van M. Darsey, of Detroit, Michigan, Assignors to Parker Rust-Proof Company, of Detroit, Michigan, a corporation of Michigan.

This patent relates to a phosphate coating for metals and particularly discusses a method by which the coating can be produced quickly

and more economically. In the present invention two baths are provided, one of which is a preliminary bath, which is rather smaller than the main bath and is frequently refreshed to retain the characteristics of a new bath. The use of a preliminary bath of great strength reduces the reaction time from normal to half or one-quarter of that usually required.

1,755,719, April 22, 1930, Pickling Apparatus, Stephen L. Williams, of Bridgeport, Ohio, Assignor to Extruded Metal Products Company, of Bridgeport, Ohio, a corporation of Ohio.

This patent describes a pickling bath and apparatus as particularly shown in the figure hereinafter reproduced. It consists of a plurality of tanks 1 adjacent to one another and a plurality of standards 2 and 3,



the center one being provided with a gear over which a chain 4 operates. The chain is provided with sufficient slack to form the loop 4A in which the apparatus to be pickled is deposited. A second loop 4A is insufficient to reach the bottom of the second tank simultaneously but by alternate rotation of the gear 5 each batch will be introduced into the pickling solution.

1,755,812, April 22, 1930, Inhibitor Material, Ludwig J. Christmann, of Jersey City, New Jersey, Assignor to American Cyanamid Company, of New York, N. Y., a corporation of Maine.

This invention relates to methods of cleaning or pickling metals by subjecting the same to an acid bath and particularly discusses an inhibitor which prevents the action of the acid on the metal after it has already cleaned the undesirable materials from the surface. The particular inhibitor disclosed herein contains a small amount of tetramethyl diamino diphenyl disulfide. In general, it is unnecessary to use more than 1 per cent; usually one-tenth of 1 per cent is sufficient. With such an inhibitor less than 6 per cent of the usual loss due to the acid takes place.

An Error Corrected

On page 731 May issue of TRANSACTIONS appeared a review of a patent granted to Frederick M. Becket Feb. 25, 1930, and noted as Patent No. 1,748,759. This review is correct in all respects excepting the patent number which should have been Patent No. 1,748,750.

News of the Society

THE COMING CONVENTION AND EXPOSITION

PREPARATIONS for the most attractive National Metal Congress ever held are rapidly being pushed to completion. Floor plans have been drawn; exhibitors have signed contracts; and space has been assigned in the immense and beautiful rooms of Chicago's Hotel Stevens.

The week of September 22, 1930, will see the Stevens filled with leaders of the metal industries, gathered for mutual benefit at the Congress and Exposition. Other societies which are cooperating with the American Society for Steel Treating will have their headquarters elsewhere in the city.

The program of papers will have as one feature this year a session on sales, scheduled for Thursday, September 25. Nitriding is again to play a prominent role in the technical program. The enthusiasm accorded the nitriding symposium held at the Cleveland convention has stimulated the Publication Committee to schedule several papers on new phases of the subject. A total of eight technical sessions, exclusive of the annual meeting and the sales session, are on the program. The Campbell lecture will be delivered at the annual meeting on Wednesday, September 24th, by Marcus A. Grossmann, metallurgical engineer of the Republic Steel Corporation, successor to the Central Alloy Steel Corporation. The subject of his paper has not yet been announced.

VOLUME XVII COMPLETED

THIS issue of TRANSACTIONS completes Volume XVII, which covers the period from January, 1930, through June, 1930. The index for Volume XVII is now ready for distribution and may be secured upon request.

Those desiring to have their loose copies of Volume XVII bound in accordance with the style used in binding Volume I to XVI, inclusive, may do so by forwarding them to the executive office of the society, 7016 Euclid Avenue, Cleveland, together with $2.00 per volume, and they will be bound and returned promptly.

TRANSACTIONS

of the American Society for Steel Treating

FEATURES

ASST

June, 1930
Vol. XVII No. 6

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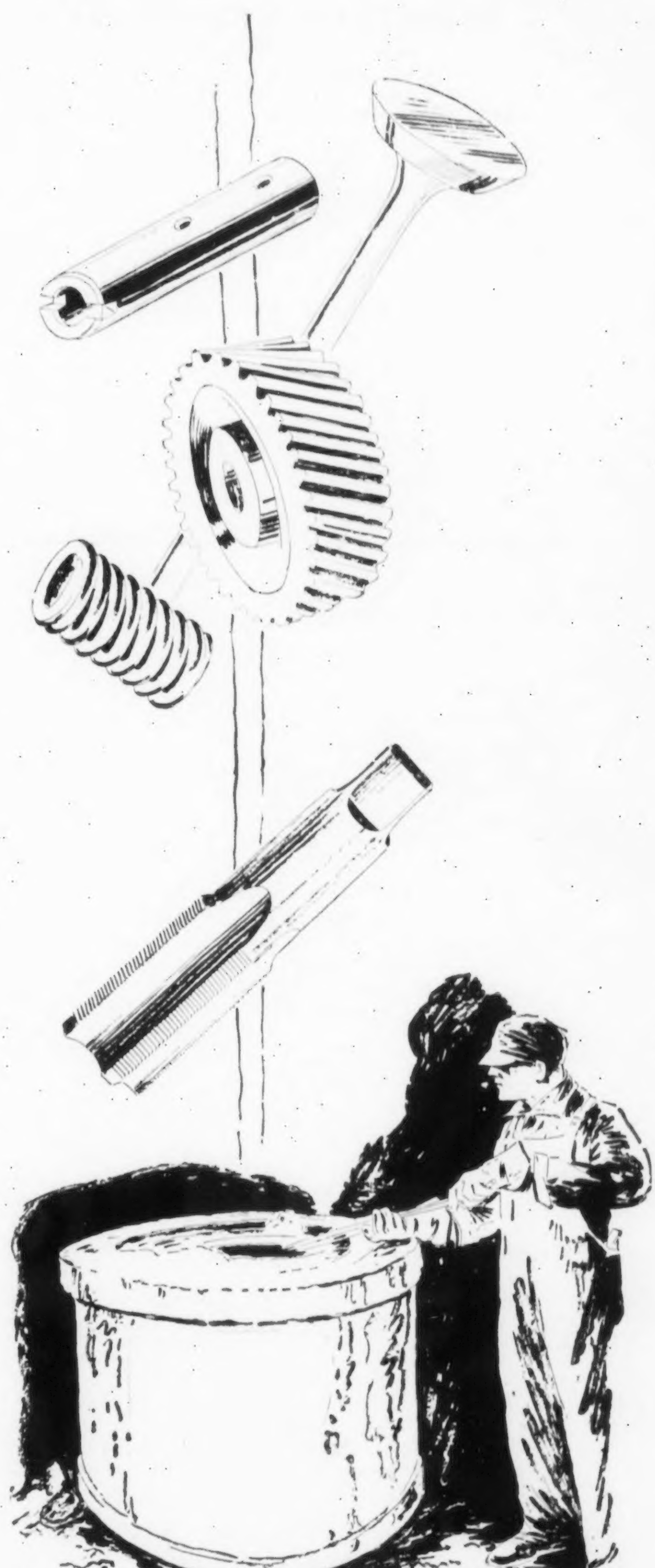

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D. means non-decarburiz- This product will neither urize nor decarburize the k if it is treated regularly Houghton's Salt Bath tifier. Melts at 1200° F., le to 1700° F.

UGHTON'S SURFACE ARDENING BLOCKS

one-ounce blocks which t at 1200° F. and are usable 1700° F. The bath has a d carburizing action and duces a hard, tough case.

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made by powdering the face Hardening Blocks, is intended for use where oduct in powdered form ore desirable. It is used nsively for sprinkling on in an open furnace to uce a thin but very hard

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News of the Chapters

STANDING OF THE CHAPTERS

THE standing of the chapters together with their membership is shown below. There were 118 new members secured during April and 271 reinstatements and 10 dropped, leaving a net gain of 372, and making the membership of the society on May 1, 1930 a total of 5,683.

GROUP I		GROUP II		GROUP III	
1. Chicago	478	1. New Jersey	227	1. Ontario	134
2. Detroit	433	2. Los Angeles	219	2. New Haven	105
3. Pittsburgh	424	3. Hartford	154	3. Worcester	102
4. New York	341	4. Milwaukee	146	4. Tri-City	84
5. Cleveland	341	5. Golden Gate	139	5. Schenectady	82
6. Philadelphia	328	6. Lehigh Valley	126	6. Rhode Island	74
7. Boston	257	7. Buffalo	116	7. Washington	74
		8. Montreal	109	8. Rochester	72
		9. Cincinnati	103	9. Columbus	55
		10. Canton-Mass.	100	10. York	55
		11. St. Louis	91	11. Rockford	55
		12. Dayton	77	12. Springfield	46
		13. Indianapolis	75	13. Southern Tier	45
		14. Syracuse	71	14. Notre Dame	36
		15. North-West	62	15. Fort Wayne	20

BOSTON CHAPTER

The Annual Meeting of the American Society for Steel Treating, Boston Chapter, was held at Massachusetts Institute of Technology, Cambridge, Mass., on Friday, May 2, 1930, dinner being served in Walker Memorial at 6:30 p. m. Immediately following dinner the annual report of the secretary-treasurer was read and the officers were elected for the year 1930-31.

The principal speaker of the evening was Robert G. Guthrie, national president of the American Society for Steel Treating and metallurgist for the Peoples Gas Light and Coke Co., of Chicago, who gave an illustrated practical talk on "Carburizing with Gas."

Wm. H. Eisenman, national secretary of the American Society for Steel Treating and well known to all the members, discussed briefly matters of general interest and stated that the 1931 convention of the society would be held in Boston. He also mentioned some of the plans for the 1930 convention at Chicago as well as those for the Western Metal Congress to be held in San Francisco next February.

Among the other guests present who spoke were National Treasurer A. O. Fulton, National Director A. H. d'Arcambal and Prof. Albert Sauveur.

Seventy members and guests attended the dinner and about 150 were at the evening meeting. *Howard E. Handy.*

BUFFALO CHAPTER

On Thursday, April 24, 1930, the Buffalo Chapter held the eighth regular meeting at Hotel Buffalo with about 35 men at dinner and about 70 members and guests at the meeting.

Chairman R. E. Sherlock called the meeting to order at 8:15 p. m. We had Dr. Shearer, librarian of the Grosvenor Library as guest, who spoke a few words about the service they can render to workers in the steel industry especially where research work is done.

After a short business session the chairman introduced the speaker of the evening, Dr. H. W. Gillett, director, Battelle Memorial Institute, Columbus, O., who talked on the subject of, "Fatigue." Dr. Gillett is one of the foremost authorities on fatigue of metals. The speaker explained clearly the phenomena of fatigue, or testing of metals under repeated stress. The reason that metals fail in service is not due to crystallization, but to progressive fractures, internal or external. Dirty steel is in poor shape to stand repeated stress. Endurance limit is reduced about one-half by improper fillets. If applied stresses are below the endurance limit, the metal is improved due to the cold working of the material. Dr. Gillett, illustrated his lecture with some very interesting slides.

The speaker kindly answered all questions at the discussion and the meeting closed with a rising vote of thanks. Meeting adjourned at 10:30 p. m.

C. F. Wahl.

CHICAGO CHAPTER

On Thursday, April 10, the Chicago Chapter entertained members of the local section of the National Die and Special Tool Builders Association. The subject for the evening's discussion was "New Welding Processes," and the whole evening proved a profitable one for those present. The speaker was Robert N. Holt, research engineer of the Fusion Welding Corp., and the technical chairman for the evening was J. B. Green, president of the same company.

Mr. Holt dwelt particularly on the process of carbon arc welding under certain particular conditions. The advantage of the carbon arc process over the metallic arc process is in being able to control the current independently of the metal itself. The disadvantage heretofore, however, has been that the carbon arc showed a tendency to jump, and scatter, causing an unsound weld. By Mr. Holt's process it is possible to control this arc by means of a special flux, and thus secure perfect welds. Thus thinner materials can be welded, and welding with heavier materials can be speeded up. Slides were shown, illustrating matters of technique in welding, photomicrographs of weld and adjacent area structures, and examples of welds. Mr. Holt also had numerous specimens on exhibition showing samples of this special welding in stainless steel, in aluminum, and in copper. Some of these were of 24 gauge material, and were beautiful examples of welding.

Prefacing Mr. Holt's lecture, Mr. Green gave a short but extremely in-

teresting coffee talk on "The Use of Infra-Red Light Photography in Welding Research." He showed pictures on the screen made with infra-red radiation, where the visible light had been filtered out. These pictures illustrated beautifully how the metal drops from welding rod to weld, and brought out points that would be invisible to the eye and obscured by visual light in ordinary photography. Mr. Green stated that motion pictures taken by this process gave an exceptionally fine view of the actual metal flow in the welding operation, and it was unfortunate that he was unable to exhibit these motion pictures.

About 100 members and guests were present at dinner, and about 175 heard the lecture.

D. L. Colwell.

CINCINNATI CHAPTER

Thursday evening, April 3, the Cincinnati Chapter held its regular meeting. At 6:15 p. m. there was a dinner at the Central Y. M. C. A. which was followed by a brief talk by G. C. Smith, safety director and assistant to the city manager.

Mr. Smith gave a talk on the subject of "Traffic." He explained the records that are being kept in Cincinnati and in other cities on the fatalities that occur by automobile accidents. Many important facts were brought out by Mr. Smith which are good food for thought.

Then at about 8:00 p. m. we adjourned from the Y. M. C. A. to hold the main subject of the evening at the Engineers' Club. We were fortunate to have Dr. H. W. Gillett, director of the Battelle Memorial Institute of Columbus, O., give us a talk on the subject of "Fatigue." His talk dealt with the failures of metals under repeated stress, how they determine the endurance and repeated stress by laboratory tests, and the factors of design which one may avoid to prevent failure under repeated stress. Also he touched upon both ferrous and nonferrous alloys, on corrosion-fatigue, and pointed out some of the pressing questions in regard to endurance on which knowledge is still too meager. Generally his talk just touched on the high spots as his time was limited. This subject was most clearly brought out by being illustrated with a number of slides.

After a very interesting and valuable discussion Dr. Gillett was given a hearty applause for the paper he so well presented.

N. C. Strohmenger.

CLEVELAND CHAPTER

The regular monthly meeting of the Cleveland Chapter was held April 14 in the Cleveland Engineering Society rooms. The meeting was called to order by Chairman White. The report of the nominating committee was made and accepted.

W. T. Donkin, chairman of the program committee, then introduced the speaker, C. C. Wales of the Otis Steel Co., who spoke on the subject of "Sheet Steels" to an attentive audience of about 100 members and guests.

Mr. Wales stressed the need for uniformity in sheet steels to insure proper drawing, non-uniform sheets causing excessive breakage. The aim of the

manufacturer should be to produce such a product that there is uniform temper in every sheet in every shipment of a definite grade of sheet steel.

This result can only be accomplished by very close control of the manufacturing. The silicon content of the open-hearth steel is closely controlled and the method of pouring the ingot is a factor. The blooming mill ingot is heated uniformly for rolling which is also closely watched.

The annealing of the sheet is a very important operation and need for closely controlled temperature and uniform temperature throughout the charge was stressed.

There has been considerable change and development in sheet manufacture in the last five years in the use of normalized sheets, continuous furnaces, continuous mills and in other directions. Mr. Wales stated these developments and others are needed to insure a uniformly controlled product.

The active discussion which followed brought out many details of the processes which Mr. Wales briefly outlined in his talk.

Preceding the meeting the regular dinner was attended by about 35 men.

W. E. Benninghoff.

DAYTON CHAPTER

The April meeting was held at the Dayton Engineers' Club on the 21st. At the usual dinner meeting Irwin W. Rohlfs, assistant prosecuting attorney of Montgomery County gave an unusual and interesting talk on "Criminals and Criminal Law Proceedure."

The main feature of the evening consisted of a talk by Ferd P. Pohlmeyer, heat treat supervisor, National Broach and Mfg. Co., Detroit on "Practical Heat Treating Experiences." Ferd was formerly one of our own active members so it was like old times to have him back again. The talk served as an introduction to a scheduled free-for-all discussion on heat treatment. With Pohlmeyer as a leader of the discussion quite a number of ideas, experiences, and problems were exchanged bringing forth several lively arguments which were stimulating and helpful.

The speaker based his talk on five points which are the links in the chain of a good tool. These basic principles are:

1. The steel from which a tool is made
2. The design of the tool
3. The way in which it is made and finished
4. The heat treatment
5. The way in which it is used.

These points were expanded and emphasized by consideration of such features as cold working of the steel in manufacture of the tool, slow heating of the tool for heat treatment, supervision and observation of the piece during heat treatment, soaking at temperature for the proper time, cooling of high speed steel before drawing, drawing slowly and uniformly, times and temperatures required for various operations, technique of quenching, and many other potent and important factors.

Mr. Pohlmeyer's talk was well received as was shown by the discussion

afterward and a rising vote of thanks was given the speaker at the close of the meeting. *George R. Long.*

DETROIT CHAPTER

The regular monthly meeting of the Detroit Chapter was held on Monday, April 21, at the Fort Shelby Hotel. The speaker of the evening was W. G. Hildorf, metallurgical engineer, Timken Steel and Tube Co. E. J. Hergenroether was technical chairman.

Mr. Hildorf was formerly metallurgist with the Reo Motor Car Co., and a member of the Detroit Chapter. He stated that changing from the consumer's to the producer's point of view had been an interesting experience and one which would probably be useful if occasion should arise to change back again. Mr. Hildorf offered a general description of the practices of the Timken Steel and Tube Co.. Among the outstanding features were extensive use of the deep-etching test; the signal success in the use of gas for carburizing bearing races; the importance of grain size; and the desirability of electric furnaces for producing steel containing more than 0.25 per cent carbon.

The paper was discussed extensively during which discussion Mr. Hildorf described a modification of the spark-test wherein material flying from the wheel is caught and examined with a microscope. This is especially useful in differentiating between carbon and alloy steels. Further details will be published at an early date.

Mr. Hildorf's firm has made more than two hundred and fifty different compositions of steel during the past year, most of which were, of course, totally unnecessary. This indicates the need of additional missionary work in furthering the use of standard specifications. *L. B. Case.*

MONTREAL CHAPTER

The last regular monthly meeting was held on Tuesday, April 22. The meeting was preceded by a visit to the new foundry of the National Bronze Co., a subsidiary of the Robert Mitchell Co. This is one of the most up-to-date bronze foundries on the continent, and chapter members were conducted through the plant by the manager of foundries and metallurgist, Harold J. Roast, and his assistants. About thirty members availed themselves of this opportunity, and were much impressed by the automatically controlled electric melting furnaces, material-handling systems, provisions for ventilation and the equipment of the testing laboratory by which very close supervision is maintained over raw materials and products.

About forty members gathered for the usual dinner at the C. P. R. restaurant, and many others came in afterwards to hear Jerome Strauss, chief research engineer of the Vanadium Corp., who gave a very interesting and well arranged talk on aluminum bronze. Beginning with the constitution diagram and metallography of the copper end of the aluminum-copper series and the copper corner of some ternary diagrams, he explained the useful limits of these alloys. He then detailed foundry practice and points in melting and molding which must be observed to produce good castings. Mr. Strauss next took up the effect of other elements on the copper-aluminum base, and the effect of

heat-treatment. His discourse was pretty much along the lines of his article published in the A. S. S. T. TRANSACTIONS in July and August, 1927, and several members who were particularly interested in the subject were impressed with the value of back numbers of our TRANSACTIONS.

Considerable discussion was evoked, votes of thanks were passed to the National Bronze Co., and welcome was extended to new sustaining members.

Gordon Sproule.

NEW HAVEN CHAPTER

The April meeting of the New Haven Chapter was held in Waterbury on April 18. During the afternoon a very interesting plant visit was held at the Farrel-Birmingham Co., Inc., in Ansonia. It was a revelation to members of our society to see the enormous castings which are being made in the above plant.

The foundry and the machine shop were the center of interest to all. We had the opportunity to witness the rigid inspection given to the immense finished and ground rolls used in rubber machines.

The get-together dinner was held in the Waterbury Club and was attended by about 40.

The regular technical session was held in the auditorium of the Chase Co. L. Thelin of the research department gave a very interesting talk on the "Effects of Lead on Copper and Various Copper Alloys." This paper will probably appear in a later issue of the TRANSACTIONS.

The Waterbury meeting was a big success and Messrs. Keshian, Card and Kemp are to be congratulated for the splendid program which they laid out.

Our last technical meeting and plant visit will be held in Bridgeport. The Sikorsky Aviation Co. are opening their doors to our chapter and a big day is looked forward to. *R. T. Porter.*

NEW YORK CHAPTER

The New York Chapter held its April meeting on the 24th with dinner served at the Postkeller restaurant in the Woolworth Bldg., and the meeting held subsequently in the assembly room of the Merchant's Association.

A report was given by Mr. Claussen of the Brooklyn Polytechnic Institute concerning his senior thesis which was made possible by an award of $100 presented each year by the New York chapter to a student interested in metallurgical research work. The subject of the investigation was the study of the oxidation of the surface of steel at high temperatures and the development of a process to prevent this difficulty.

The main speaker for the evening was Dr. Zay Jeffries whose talk covered "The Metallurgist in Industry." Dr. Jeffries said that the first use of metals was in their native state such as gold from placer deposits and iron weapons made from meteorites. The rise of western civilization came about through metallurgy as it was in Europe that armor was developed and by this means was Genghis Khan and his Mongols defeated.

The development of the railroad industry gave a tremendous impetus to the quantitative side of metallurgy but, with the advent of the automobile,

metallurgy took on a qualitative aspect. Since that time we have witnessed the important part played by metals in the communication industry such as the telephone and telegraph, the electronic industry as exemplified by radio, television and facsimile transmission and the whole field of aviation. One novel idea resulting from these great advances has been the standardization of parts which has become a basic requirement in American industrial work.

Dr. Jeffries finished his talk by discussing specialization in technical work. He urged metallurgists when requesting money for development work from executives first to be sure of their facts and then to make their requests positive and to stand their ground. All members were most enthusiastic over Dr. Jeffries' talk. *F. H. Clark.*

NORTHWEST CHAPTER

The April meeting of Northwest Chapter was held at the Engineering Auditorium on the University of Minnesota campus on the evening of April 15. Geo. A. Richardson, of the Bethlehem Steel Corp., gave an illustrated lecture on the manufacture of structural steel shapes.

Mr. Richardson had nine reels of new movies illustrating the various steps in steel making from the handling of the raw materials to the finished product in the stock yard. The movies were taken at various Bethlehem plants including the ones at Buffalo, Lebanon, Bethlehem, and Sparrows Point. The pictures were very interesting and Mr. Richardson explained the various processes in words that everyone could understand. One of the unusual scenes showed the operation of a gigantic semi-automatic punch press which punched rivet holes in a large steel plate according to a pattern that resembled a player piano roll.

About 400 members and friends filled the auditorium to capacity. The lecture was also given in St. Paul at the Carrick Theatre before another capacity crowd. *H. S. Jerabek.*

PITTSBURGH CHAPTER

The May meeting of the Pittsburgh Chapter was held at the Keystone Athletic Club, Thursday evening, May 1.

After the usual dinner the meeting was called to order by Chairman Richards. The annual report of the treasurer was read and approved. The newly elected officers took their places at this meeting.

T. Holland Nelson was the speaker of the evening. His subject was "Heat and Corrosion Resisting Steel." The subject was very thoroughly covered and was well illustrated with slides.

Although it was a very warm evening we had a large audience.

H. L. Walker.

RHODE ISLAND CHAPTER

The seventh meeting of the season was held Wednesday evening, April 16, 1930, at the engineering building of Brown University in Providence, R. I. This meeting was in the nature of a joint meeting of the Rhode Island Chapter and the Providence Engineering Society. There were 165 people in attendance. The meeting was preceded by an informal supper at which 18 attended.

After a brief business meeting, Dr. Victor O. Homerberg of the Massachusetts Institute of Technology, was introduced and gave a highly interesting talk on "The Nitriding Process of Surface Hardening Steel."

The successful operation of this process necessitates special alloy steels made for the purpose. Alloy steels containing varying amounts of carbon, together with approximately 1.0 per cent aluminum, 1.0 per cent chromium, 0.2 per cent molybdenum have been found to give the maximum surface hardness.

The principle of the nitriding process as explained by Dr. Homerberg is the formation of nitrides of the alloy elements which are extremely hard and form needle-like crystals at the surface of the steel. The function of the ammonia is to furnish nascent nitrogen by partial dissociation which is very active.

The nitriding process is very flexible and varying degrees of hardness, ductility and depth of surface can be obtained by varying conditions.

The work to be nitrided is first completely machined and heat-treated to impart desired physical properties to the core as usual. Before nitriding all strains set up by forging or machining must be relieved by proper annealing. Scale and decarburized surfaces must be avoided. Surfaces that are to be protected from nitriding are nickel plated or otherwise protected.

The parts to be nitrided are placed in a gas-tight box made of special alloy not affected by ammonia. The box is equipped with inlet and outlet tubes for ammonia circulation and thermocouple for checking temperatures inside box. The box is placed in a furnace of suitable design and heated to desired temperature. The range of temperatures in use varies from 900 to 1100 degrees Fahr.—950 degrees Fahr. being most common. Anhydrous ammonia gas is circulated through the work and the pressure regulated to give proper dissociation which is checked by a special apparatus on the exhaust ammonia line. Dissociation is kept between 20 and 40 per cent. The time and temperature are varied depending upon the depth and character of case required.

Dr. Homerberg's talk was illustrated by lantern slides and several comparative tests between case carburized and nitrided articles were presented.

Refreshments were served after the meeting. *Wilton Brown.*

WASHINGTON-BALTIMORE CHAPTER

The March monthly meeting of the Washington-Baltimore Chapter was held at Washington on Friday evening the 21st. The usual dinner in honor of the speaker was served at the City Club.

The speaker of the evening, Dr. S. L. Hoyt of the General Electric Research Laboratory, spoke on "Cemented Tungsten Carbide" before a fair sized group in the East lecture room at the Bureau of Standards.

The extreme interest in Dr. Hoyt's talk was evidenced by the general discussion that followed. The chapter considered it a privilege to have a man of Dr. Hoyt's ability and experience address them on this metallurgical phase.

A special "Pep" meeting of the Washington-Baltimore Chapter was held in Baltimore on March 31. The purpose of this meeting was to give the metallurgists, plant and tool men a chance to become acquainted with the

members and to show them the benefits derived by belonging to the American Society for Steel Treating. Walter Dietrick of the membership committee handled this latter phase in a very amiable manner. The usual dinner was served at the Engineers' Club and was attended by about 50 members.

Through the courtesy of the Consolidated Gas Co., the meeting was held in the auditorium of their new building, where a large sized group listened to Arthur Green, manager of the tool department, Edgcomb Steel Co., deliver a very interesting talk on "Tool Steel."

Mr. Green covered the subject of tool steels in a very thorough manner; starting with their manufacture, mill routing, inspection, heat treatment, and their use. Many of these steps and points were illustrated by lantern slides as well as a series of photomicrographs showing the various structures resulting from the above operations. Mr. Green cited many examples of tool failure that he had run across in practical "trouble shooting" and ended with a plea for a greater co-operation between producer and consumer whereby much trouble which tended to prohibit successful application of tool steels could be eliminated.

A short adjournment took place, followed by refreshments, after which a good half hour's discussion followed. A rising vote of thanks was extended to Mr. Green for his interesting and instructive talk.

The year's work of the membership committee is slowly being realized as a gradual increase in members and sustaining members is noted, though the chapter is still far behind in the total number that should be in the American Society for Steel Treating from Washington and particularly Baltimore.

Leo J. Waldron.

A most interesting and unusual lecture on the construction of the Hudson River Bridge was presented before the Washington-Baltimore chapter by Edw. W. Stearns, assistant to the chief engineer of bridges of the Port of New York Authority, at the Engineer's Club in Baltimore, on April 18.

Starting with a short account of the formation, scope of work, and method of financing of the Port Authority, the speaker described, with the aid of about thirty slides and three reels of motion pictures, the "high spots" of the construction of the Hudson River Bridge to date. This bridge, which crosses the Hudson River between 178th and 179th streets in New York City and Fort Lee in New Jersey, is the largest suspension bridge in the world. It has a main span of 3500 feet, the towers are 625 feet high, the clearance at the center of the bridge is 213 feet, the road level is 250 feet above the river, and the width of the bridge is 120 feet. The span is supported by four cables each containing 61 strands and laid in a hexagonal shape but later squeezed into a compact cylindrical form. Each strand consists of 434 wires about $\frac{1}{10}$ inch in diameter. The wires are cold drawn to an ultimate strength of 235,000 pounds per square inch and have a proportional limit of 160,000 pounds per square inch. The wires are heavily galvanized and have a working stress of 82,000 pounds per square inch. The bridge was designed for an addition of a lower floor accommodating four rapid transit lines when necessary.

The motion pictures illustrated the digging of the foundation, the erection

of the towers, the laying of the foot bridges, the spinning of the cables, etc., and were unusually instructive.

A lively discussion followed the talk and a rising vote of thanks was given the speaker.

Samuel J. Rosenberg.

YORK GROUP

The March meeting of the York Group of the American Society for Steel Treating was held Wednesday, March 12, 1930, in the rooms of the York Engineering Society at York, Pa. There was a total attendance of sixty-five including members and guests.

The address of the evening was delivered by Frank R. Palmer, assistant to the president of the Carpenter Steel Co. He selected as his subject, "The A B C of Stainless Steels." Mr. Palmer told of the three general groups of stainless steel, namely A B and C. Each group of stainless metals is characterized by certain properties which are common to all steels falling in that group. The analysis of the A group is as follows:

Chromium less than 14 per cent
Carbon less than 0.40 per cent

The B group as follows:

Chromium more than 16 per cent
Carbon less than 0.40 per cent

The C group as follows:

Contains enough chromium and nickel to make a steel austenitic and non-magnetic.

A paper was then distributed among the members and guests giving a thorough outline of corrosion resisting steels.

In a long discussion that followed the paper many presented their problems to Mr. Palmer, who in turn answered all problems and arguments.

After a rising vote of thanks to Mr. Palmer, the meeting was adjourned.

Ernest G. Wigfield.

The April meeting of the York Group of the American Society for Steel Treating was held at the Colonial Club at Harrisburg, Pa., Wednesday, April 9, 1930. The meeting was attended by eighty-five members, sixty-five of which were present to enjoy a dinner preceding the lecture.

The speaker for the evening was Dr. Norton, metallurgist for the Ludlum Steel Co. He chose as his subject "Nitriding and Steels for Nitriding."

Dr. Norton read a paper stating that the nitriding process consists in subjecting special steels containing aluminum, chromium and molybdenum to the action of ammonia gas under certain conditions whereby a remarkable surface hardness is imparted to the steels without further treatment. Remarkable wear-resisting properties combined with retention of hardness at elevated temperatures and marked resistances to atmosphere, water and salt water corrosion are obtained.

After this paper was read slides were shown illustrating the various steels being nitrided and the many processes being used.

A lively discussion of the phases of nitriding followed.

Ernest G. Wigfield.

Items of Interest

THE Southern Manganese Steel Co. has become the Southern Manganese Steel Division of the American Manganese Steel Co. An office has been opened in the Law and Finance Bldg., Pittsburgh, in charge of W. G. Hoffman. Mr. Hoffman will handle the sale of manganese steel castings, and heat and corrosion resisting castings.

Ryan, Scully and Co., Philadelphia, have just completed plans for new office and manufacturing buildings which will more than triple the present facilities. With the new facilities the company will assemble equipment and ship direct from the plant instead of assembling equipment on the job as was done previously.

"Gemeinfassliche Darstellung des Eistenhuettenwesens" (The Story of Iron and Steel) is a 728-page book published by the German Iron and Steel Institute, Duesseldorf. Engineers wishing to visit Germany will find it useful in becoming acquainted with German technical terms and also because of the list of German iron and steel works, including sizes and capacities of furnaces and rolling mills.

Southwark Foundry and Machine Co., 400 Washington Ave., Philadelphia, has issued a bulletin briefly describing Southwark-Emery testing machines.

"Automobile Steels" is the title of a 219-page book by Muller-Hauff and Stein published by John Wiley and Sons, Inc., 440 Fourth Ave., New York. This book was translated from the German. It contains an additional chapter on S. A. E. standards, on test specimens and steel specifications, fractures of automobile parts, and 13 tables furnished by American and European automobile plants. The price is $3.50.

The Ludlum Steel Co., Watervliet, N. Y., has issued a new catalog. This consists of a binder, in which are general and special catalogues. Additional space is provided for the insertion of new catalogues or other data which may be issued from time to time.

The Claud S. Gordon Co., of Chicago has announced the purchase of the Cleveland Instrument Co., 1988 East 66th St., Cleveland, and the General Pyrometer Supply Co., 2902 Carnegie Ave., Cleveland. The Claud S. Gordon Co., will operate the new consolidation under the name of Pyrometer Service and Supply Corp., and will be located at 1988 East 66th St., Cleveland. This office will be able to ship from stock, instruments, protecting tubes, lead wire, thermocouples, etc.

St. John X-Ray Service Corp., 505 Fifth Ave., New York, has been

organized by Ancel St. John and Herbert R. Isenburger, to carry on the X-Ray inspection and sales business hitherto conducted by them.

The Crucible Steel Co. of America announces the appointment of John F. Taylor as district representative in charge of their new district office at 812 State Trust Bldg., Moline, Ill. Mr. Taylor has been connected with their Chicago office for the past 17 years.

The University of Illinois, in co-operation with the Illinois Gas Association, will hold its fifth annual short course June 16 to 28. The curriculum covers eight hours a day of practical modern gas engineering presented by leading authorities in gas and allied industries.

Applications for enrollment may be had by writing to George Schwaner, secretary Illinois Gas Association, 405 Mine Workers Bldg., Springfield, Ill.

A 12-page booklet "Alloy Steels in the Railroad Field" may be obtained by addressing a request to the International Nickel Co., 67 Wall St., New York.

The Surface Combustion Co., 2375 Dorr St., Toledo, O., has announced a $250,000 expansion program. With the acquisition of new property and the enlargement of present buildings the plant will include 9 acres of land and 4 acres of floor space. This company has built much of the heat treating equipment used by the steel, automotive and machinery manufacturers throughout the country.

Microvernier oil regulating valves are described in a leaflet issued by Hauck Mfg. Co., 126 Tenth St., Brooklyn, N. Y.

Continuous electric furnaces for heat treating strip metal and wire are described in a booklet by H. O. Swoboda, Inc., 3400 Forbes St., Pittsburgh.

The Brown Instrument Co., Philadelphia, announces the consolidation of its Chicago sales office and mid-western factory branch in new quarters at 155 East Superior St., Chicago.

E. J. Lavino and Co., Philadelphia, has available to those interested, copies of Nielsen Surveys Nos. LC-104-C2 and LC-102-H2. These cover the application of plastic bottoms in forging furnaces and the use of multi-bond chrome ore cement in the Rockford Drop Forge Co., and the Camden Forge Co.

"Carbon Determinations in High-Sulphur Steels" is the title of a short article appearing in *The Laboratory*, a publication issued by the Fisher Scientific Co., Pittsburgh.

Artificial abrasives fall chiefly into three main groups, according to the United States Bureau of Mines, Department of Commerce. These are: Metallic abrasives such as crushed steel, steel shot, and steel wool; silicon carbide abrasives such as carborundum, crystolon, and carbolon; aluminum oxide

abrasives such as alundum, aloxite, exolon, and lionite. The metallic abrasives are used chiefly in loose form as cutting agents in sawing or drilling rock and other hard materials. A very important use of the silicon carbide and the aluminum oxide abrasives is in the manufacture of bonded abrasive wheels. The abrasive grains graded into uniform sizes are bonded together into wheels of varying degrees of coarseness and hardness. A fusible clay is used as the bonding material in vitrified grinding wheels. Sodium silicate, shellac, and bakelite are also employed as bonding materials. Much progress has been made in recent years in the development of highly efficient abrasive wheels; they are being used more and more as substitutes for natural abrasive products such as emery wheels, grindstones, and pulpstones.

An artificial abrasive consisting of tin oxide or a mixture of tin oxide and oxalic acid has been termed "putty powder." It is used for polishing marble and granite. Rouge and crocus, both of which are forms of ferric oxide, are employed to produce a high luster—the former on precious metals and the latter on tin and cutlery. Chromium oxide, manganese dioxide, and magnesia have limited use as abrasives.

The Hevi Duty Electric Co., Milwaukee, has just published a six page bulletin No. 430 covering eighteen standard sizes of box type electric furnaces. The bulletin gives complete descriptions and specifications.

The widespread use of the mechanical appliance known as the valve, and the important part it plays in every branch of industry and in the home itself, is illustrated interestingly in an educational motion-picture film entitled "Open and Shut," prepared by the United States Bureau of Mines, Department of Commerce, in cooperation with an industrial concern.

"Valves are absolutely essential in central power stations, and blast furnaces, and hydraulic mining, and steamships, and airplanes, and fast trains, and spray painting," explains the narrator, as interesting views of these are flashed on the screen.

Copies of the film, "Open and Shut," may be obtained for exhibition purposes by schools, churches, clubs, civic and business organizations, and others interested by applying to the Pittsburgh Experiment Station of the United States Bureau of Mines, Pittsburgh, Pa. No charge is made for the use of the film, although the exhibitor is asked to pay transportation charges.

An electric furnace for pressure carburizing has been placed on the market by the Hevi Duty Electric Co., Milwaukee. It is a rotary retort type of furnace perfected after four years of field development, and is licensed under U. S. patents by the American Gas Furnace Co. Sizes are furnished up to 1200 pounds capacity. The furnace is mounted on sturdy steel legs with an operating mechanism which permits tilting backward and forward to facilitate charging and discharging. Insulated plugs are used to close the retort both front and rear, being easily removable for free access for loading and unloading. Three zones of control are provided to secure an even temperature throughout the length of the retort. Pyrofax gas under pressure is normally used, and is cracked into hydrocarbons and absorbed by the steel charge. Artificial and natural gas as well as carburizing compound are as readily used.

The furnace is also used for hardening operations, and has successfully nitrided steel bars of a dimension to require a furnace chamber of extreme length with small diameter.

In 1929 a total of 419,400 short tons of molybdenum ore was milled yielding 3,854 tons of concentrates, carrying from 75.40 to 88.33 per cent molybdenum sulphide. In addition, a small tonnage of ore carrying 16 per cent of molybdenum sulphide was produced and sold without milling. The metallic molybdenum content of the concentrates and ore so produced was 4,020,607 pounds, an increase of 17 per cent over 1928. The shipments of concentrates and ore from the mines contained an equivalent of 3,904,648 pounds of elemental molybdenum valued, more or less arbitrarily, at $2,259,000 at the mines.

Climax Molybdenum Co., 295 Madison Ave., New York, has issued a book "Molybdenum in 1929." This presents data in the form of extracts and abstracts from technical publications.

"Misco High Temperature Alloy" is the title of a recent booklet issued by the Michigan Steel Casting Co., Detroit.

The symposium on aircraft materials to be held at the thirty-third annual meeting of the American Society for Testing Materials, which will be held June 23 to 27 at Chalfonte-Haddon Hall, Atlantic City, N. J., is of unusual interest to members of the A. S. S. T.

Through the efforts of a committee under the chairmanship of H. C. Knerr, functioning in an advisory capacity to the committee on papers and publications, a very excellent program has been arranged for the symposium on aircraft materials. Seventeen papers have been secured, each one briefly summarizing the present knowledge on some phase of the properties or testing of aircraft materials. These cover not only the materials for the structural members but also the materials entering into aircraft engines, including engine failures and the causes thereof.

Production and consumption of copper, which assumed record-breaking proportions in the fall of 1928, continued at a high rate through 1929, according to the United States Bureau of Mines, Department of Commerce, and for the year were the highest on record. Heavy demand preceded the large increase in production and was met, in part, by stocks of refined copper, which at the end of 1928 had dwindled to the lowest on record since 1917. In 1929, production was at a sufficiently higher rate than consumption to cause stocks of refined copper to increase to more than two and one-half times those at the end of 1928 and to the highest on record since the end of 1921. The increase in imports of unmanufactured copper to a record figure and a drop in exports of 7 per cent from the average of the five-year period 1924-1928, added to the large increase in stocks. At the end of the first quarter of 1929, stocks of refined copper having increased, consumers resumed a hand-to-mouth buying policy which had been abandoned in the fall of 1928.

Copper prices rose from a monthly average of 13.9 cents a pound in January, 1928, to 15.9 cents in December, the advance continued to a high of 23.775 cents, at refinery, March 23, 1929, where it held until April 5. During April it dropped to 17.775 cents and remained beyond the end of the year.

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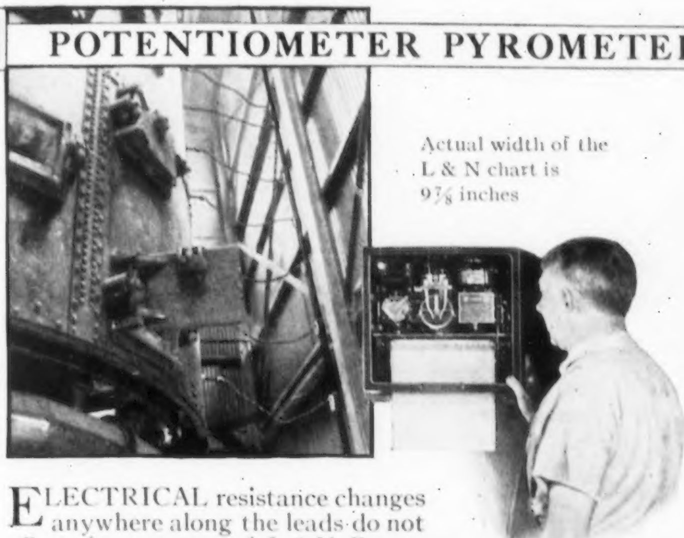

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Ray T. Bayless, *Editor*

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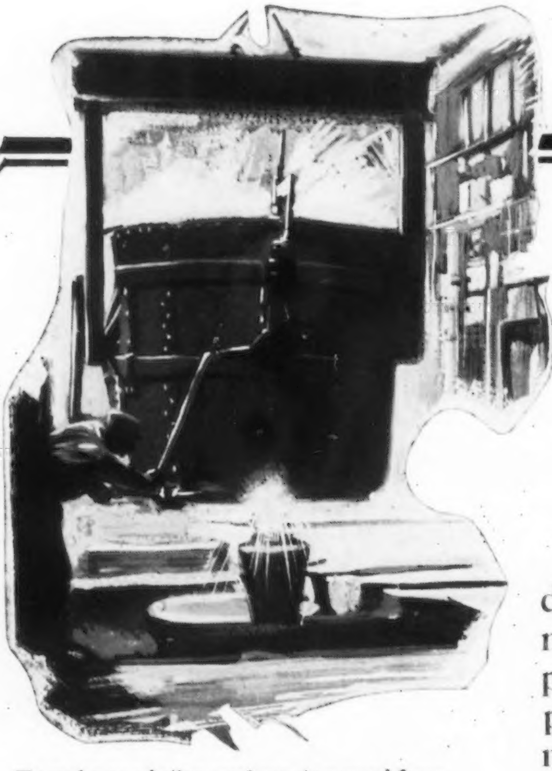

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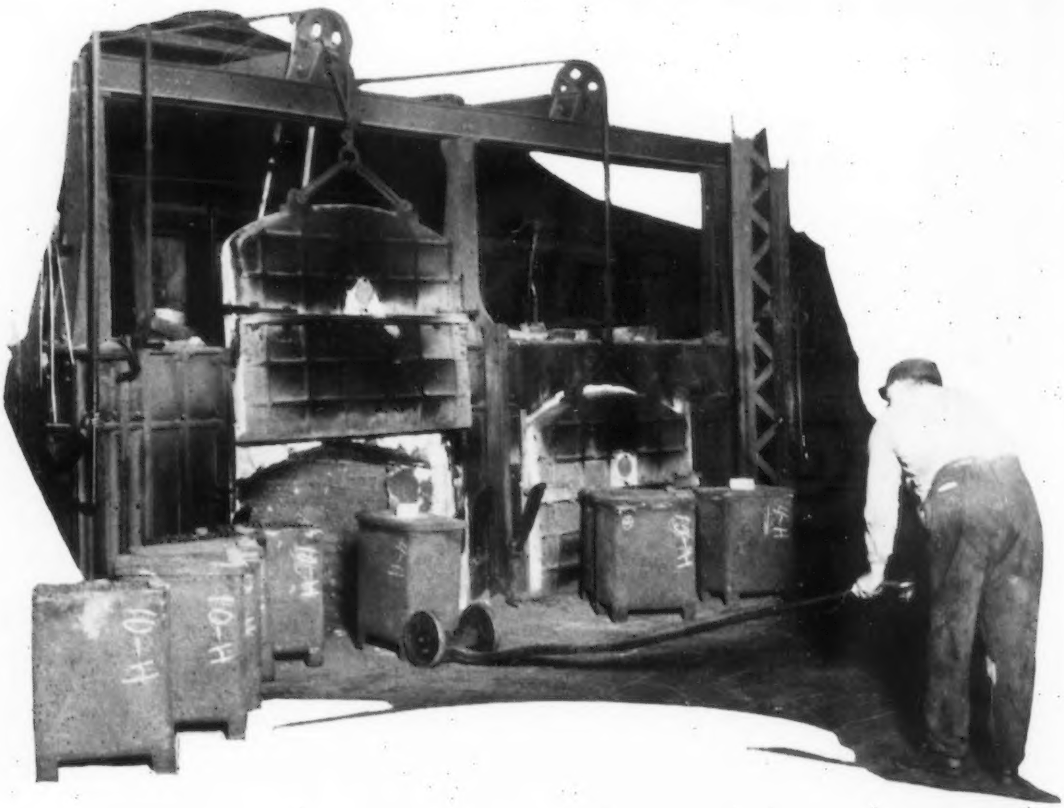
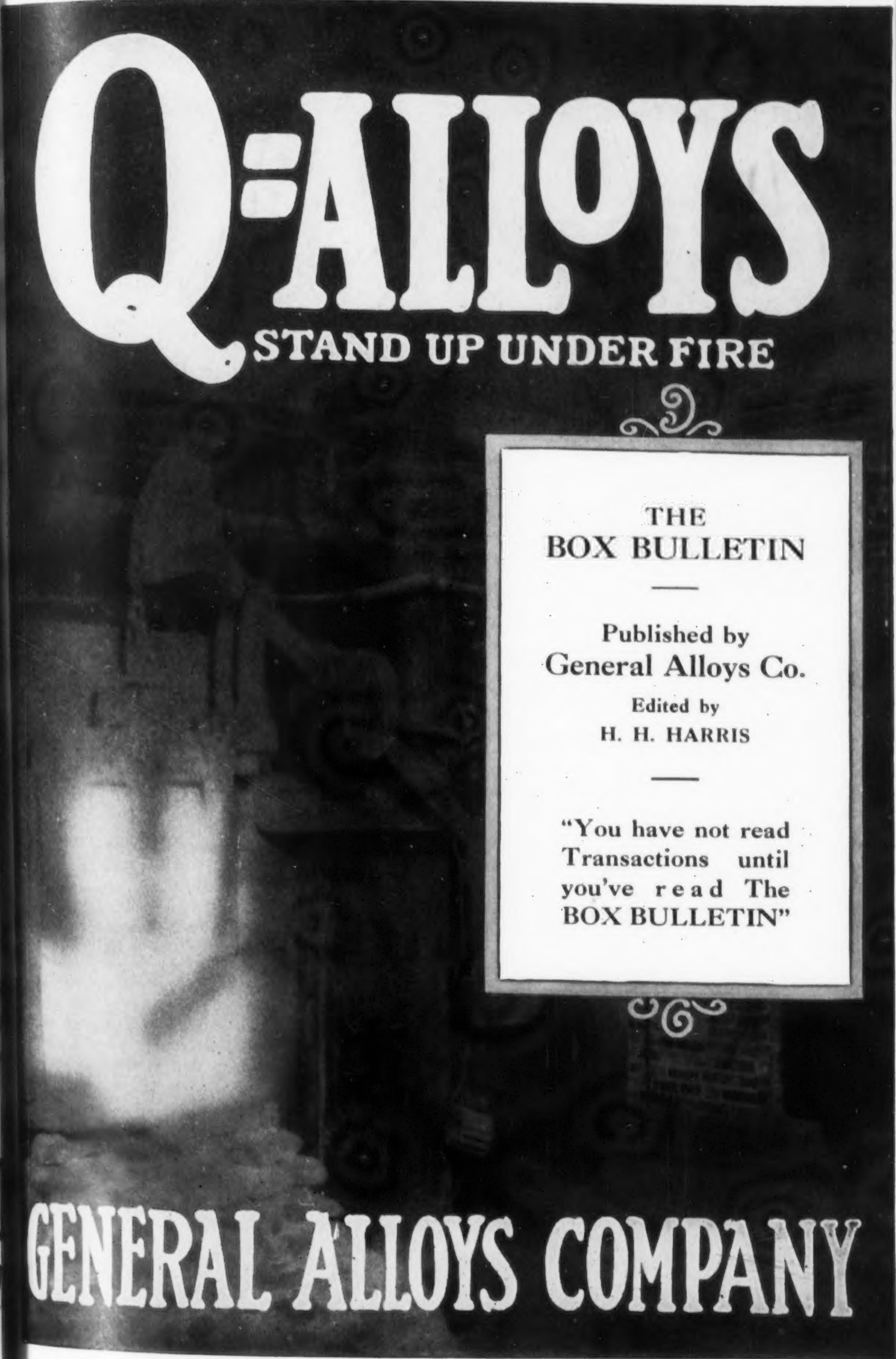
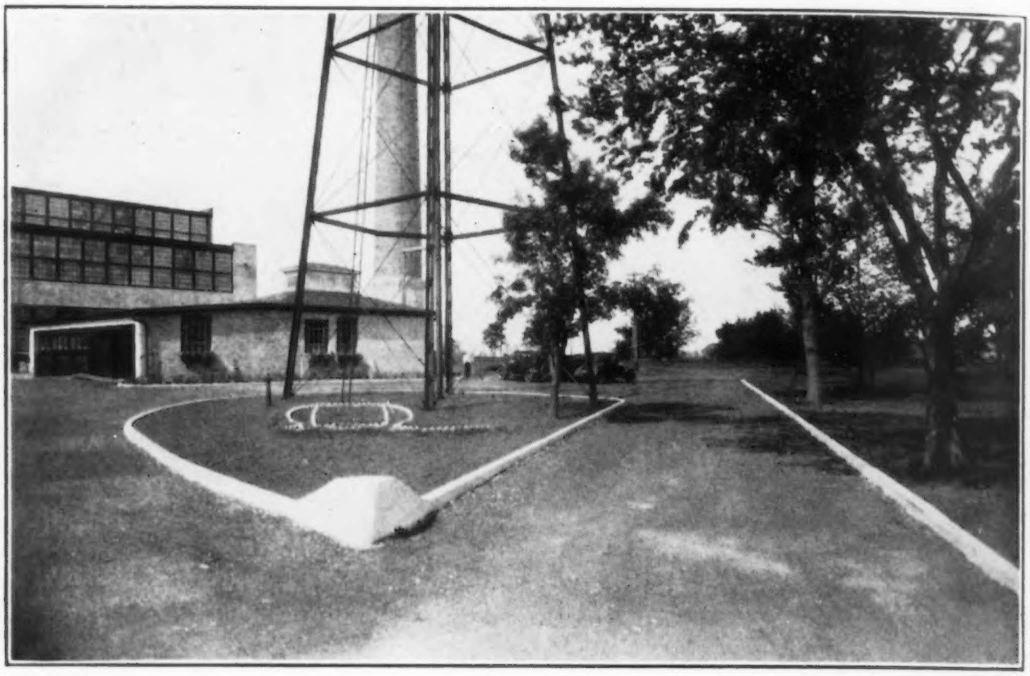



Q-ALLOYS
STAND UP UNDER FIRE
THE
BOX BULLETIN
Published by
General Alloys Co.
Edited by
H. H. HARRIS
"You have not read
Transactions until
you've read The
BOX BULLETIN"
GENERAL ALLOYS COMPANY

BOX BULLETIN SUPPLEMENT PAGE II



SUMMER has just turned the corner into the South gate of the new General Alloys No. 2 plant at Champaign. Our floral "Q" in the approach drive is just coming into bloom, song flows freely from our contented birds, well fed on grass seed for the past two months.

John, our shovel artist, who unloaded the car of molding sand singlehanded in six hours, has now turned his attention to gardening, tucking in 600 barberries, 12000 primroses, numerous shrubs with loving care and uprooting dandelions with maniacal fury.

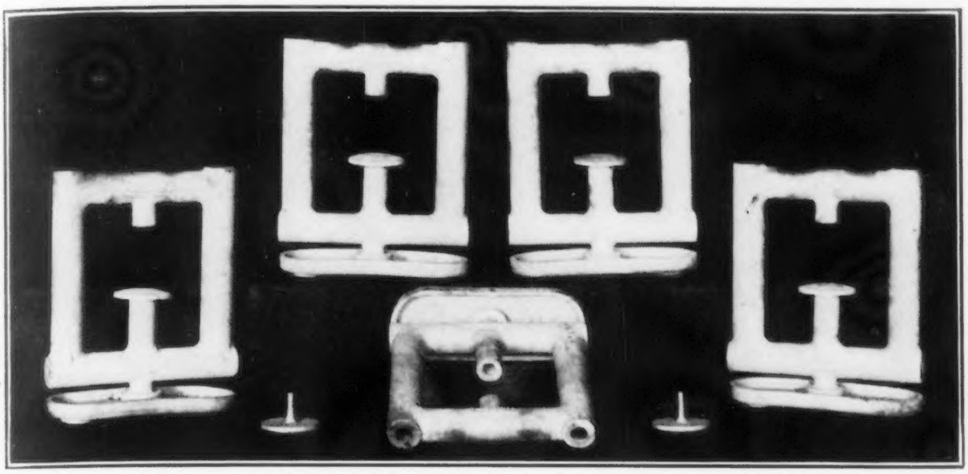
John knows his onions, but one problem stumped him. He'd worked hard for weeks preparing a grass bed with sewerage concentrate, peat moss and sand;—watched patiently for grass. When the "Grass" came up it had scalloped leaves with fuzz on 'em. Conference with Botanists revealed that we have six acres of tomato plants, and that fig trees, gooseberries, apples and cantaloupes are showing up in spots. We expect poppies, strawberries, popcorn and prunes. Figure this one out and send in your solution.

We Farmers were all going down to look at the Electric Furnace Company's new Hay Burning furnace near us in the corn-belt last week, but R. Benzinger, the Author, got his thumb caught in a slide rule and couldn't conduct the inspection. Originally designed to burn Corn-Stalks, this Kentucky model Electric Furnace can be converted for Hay burning by merely reversing the hot-air valve. It was built for niteriding, but will store furs through the summer months for 3% of owner's valuation. (No we're not kidding, see specifications in future issue.)

"You can't fuel all of the people, all of the time," says Mr. Benzinger, and we have to admit that the smart ones specify Q-Alloy boxes.

Visit us in September and pick a load of Primroses.

H. H. Harris



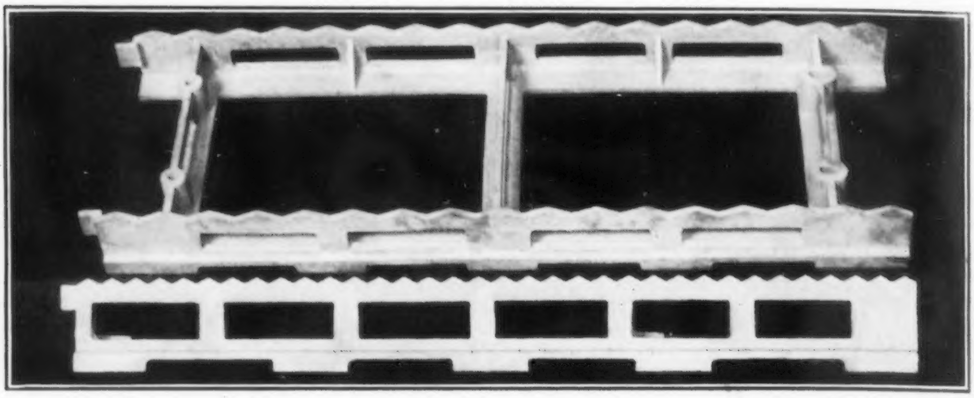
"Carburetor, Burner and Flame Diffuser"

is the official title of the above example of fine Q-Alloy foundry practice. It makes gas from oil, and burns it efficiently and uniformly.

Quite a job for a single casting—but Q-Alloy castings are doing exacting jobs—doing them well on thousands of applications.

Uniform heat transfer, means uniform wall section. Uniform temperature means orifices that stay put, remaining true to calculated expansion sizes after thousands of hours of service.

If you have need for fine alloys to do exacting work, or even if you think you can *get by* with inferior alloys, give us a chance to discuss your problems.



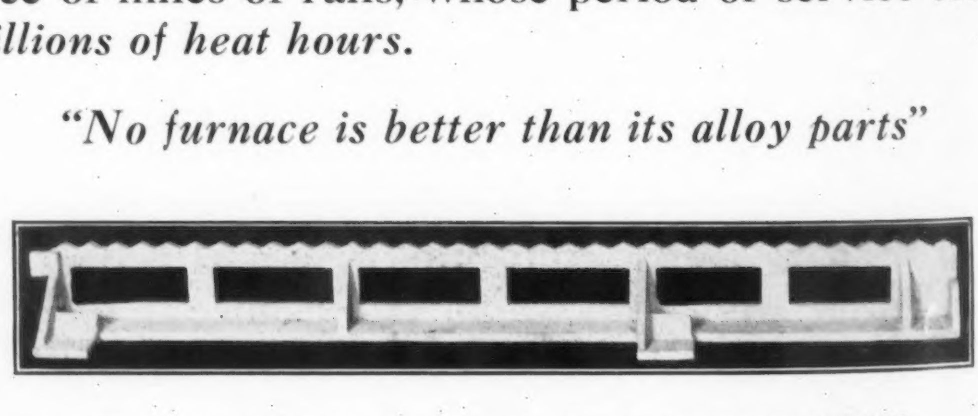
Non-Skid Rails

WE'VE shown you a lot of Skid-Rails in these pages, now take a look at some *non*-skid rails.

These rails are used under conditions that differ greatly from the usual pusher furnace rail. They are heated differently and must transfer maximum heat, allowing heat circulation to all points of work processed.

We have made more furnace rails "Accidentally" than any other alloy manufacturer has "On purpose," and only for the reason that Q-Alloy dependability is an *established fact*, backed by the performance of miles of rails, whose period of service totals *millions of heat hours.*

"No furnace is better than its alloy parts"



Carburizing Containers

THE best of design, material and workmanship is as productive of economy in Carburizing boxes as it is in Shoes, Bearings, or Tires.

The fact that the largest installations of Carburizing boxes in the World are Q-Alloys is testimony, millions of dollars worth of testimony,—that *"the best is ultimately cheapest."*

At a time when there is much conservative buying, our business is always good, for when people really try to save they seek value, not bargains, and the sale of high quality materials increases.

You must be *prosperous* to *afford* "cheap" substitutes.

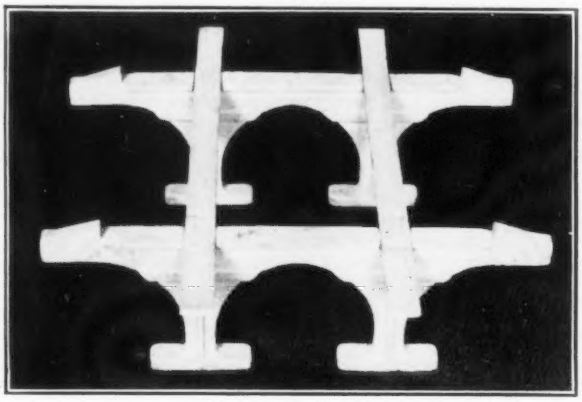
CLEVELAND to NEW YORK
3 hrs. 23 min.

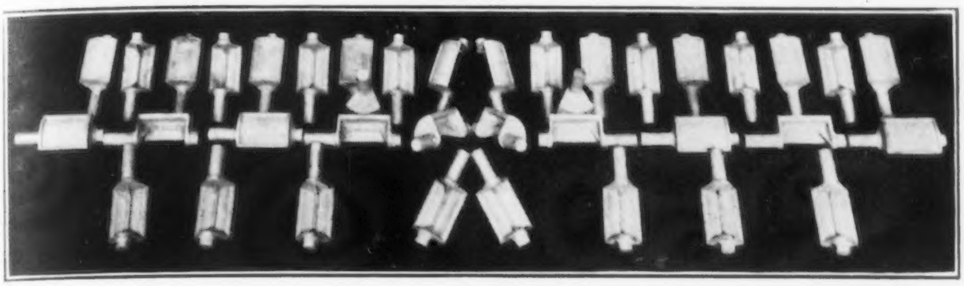
ONE of our smoothest flights this year was from Cleveland to New York last week in three hours and twenty-three minutes. Straight as an arrow, many times faster.

NC-448-H, recovered and repainted since her trip to Mexico, is back on the job, and NC-4185 is just getting a complete overhaul and a new overcoat. Both six passenger Stinson planes help our organization to "Go places and do things."

Dal. now Major

"Dal" hates "Rank," but we can't help mentioning that he's just been promoted to Major in the U. S. Air Corps Reserve. His age kept him from majoring sooner. Dal is now on his thirteenth year in the air.





Does a hole get larger or smaller under heat?

IN designing pins and bushings, pit type chains, and a variety of doweled and bushed mechanism, the expansion ratio of the pin to the hole is one of the most vital factors involved.

Plug type valves offer special problems to the designing engineer, particularly when they must remain gas tight through a considerable range of temperature change.

When such plugs, or valves deviate from the round, taking on semi-circular, or irregular shapes, the expansion problems are multiplied.

When they must be operated both hot and cold, and throughout their operating temperature range, and the leverages and abutments calculated with varying "surface adhesion" under oxidizing conditions,—hand the job to a specialist.

Your alloy requirements may be far less exacting than the machined Q-Alloy valves shown above,—even the "Simple" ones often have catches. Consult the only engineering organization in the alloy business.

Employment Service Bureau

This bureau is for all members of the Society. Want ads will be printed at the following rates: minimum of 30 words $0.50; each additional word $0.02.

This service is also for employers, whether members of the Society or not. Rates for this service are as follows: minimum of 50 words $1.00; each additional word $0.02. Fee must accompany copy.

Address answers care of AMERICAN SOCIETY FOR STEEL TREATING, 7016 Euclid Ave., Cleveland, unless otherwise stated.

POSITIONS WANTED

YOUNG METALLURGIST with ten years experience in iron and steel industries as metallurgist, chemist, engineer of tests, in charge of heat treatment and sales service, desires an opening in production or sales. Address 5-10.

YOUNG MAN, 22, with three years experience and responsibility heat treating of steel. High School graduate, engineering course, desires connection where possibility of advancement is not restricted to a heat treater. Address 6-5.

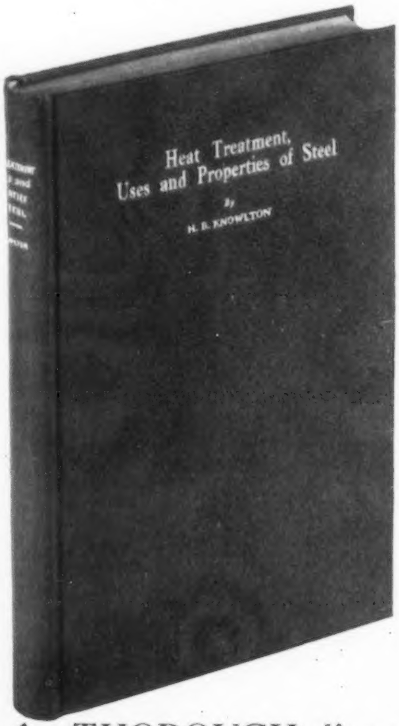
WANTED A POSITION selling. Have been employed for the past 14 months in the metallurgical laboratory of a steel company, doing microscopic work, macrographing and heat treating. Graduated from high school five years ago. Had some selling experience in different line. Address 6-15.

COLLEGE GRADUATE with degrees in chemistry and metallurgy. Eight years' experience in manufacture and heat treatment of tool and alloy steels. At present employed, desires change. Address 6-20.

POSITIONS OPEN

STEEL METALLURGIST: large and progressive corporation seeks graduate metallurgist with one to five years steel work experience, to aid in alloy steel development, location, New York. References and details of experience desired in reply. Address 6-10.

TOOL STEEL SALESMAN for Chicago, Detroit or Cleveland territory. Must have selling experience. One with metallurgical, heat treating or machine shop experience preferred. State age, married or single, past and present employers, experience in full, phone number. Address 6-25.



Heat Treatment, Uses *and* Properties of Steel

BY

H. B. KNOWLTON

Metallurgist of the Fort Wayne Works of the International Harvester Co.

A THOROUGH discussion of the processes used in heat treating and of the specific uses of the various types of plain carbon and alloy steels. It is written in understandable language for the benefit of production men and those who are not trained in metallurgy. Each process and type of steel is considered separately to emphasize its particular usefulness and to clarify the reader's ideas of its adaptability.

The author has spent 12 years in factory work, and for several years taught these subjects to production men who had no training in chemistry or metallurgy. This book is the result of years of experience in using heat treating methods and special steels, and in teaching their uses.

CONTENTS

- physical properties defined
- what is heating and quenching
- high carbon steel
- tool steels
- causes of failures
- warping and cracking
- hardening
- differential hardening
- low and medium carbon steels
- nickel steels
- chromium steels
- nickel-chromium steels
- fractional percentages of manganese in steel
- manganese steels
- vanadium steels
- molybdenum steels
- case hardening
- steels for case hardening
- heat treatment of case hardened parts
- materials and equipment for case hardening
- errors in case hardening
- heat treating equipment
- heat treating methods
- heat treating equipment for mass production

427 pages with 94 illustrations *Cloth bound, 6x9*

Price $4.50, postpaid in the U. S. A. Foreign, $4.75, postpaid

Send your order, accompanied by check to

American Society *for* Steel Treating

7016 Euclid Avenue Cleveland, Ohio

ENGELHARD—

Thermo-Elements — for superior e.m.f. characteristics —homogeneity — hardness —constancy of calibration under prolonged heating.

Years of constant research in collaboration with our affiliated companies have resulted in the high standard of Rare and Base Metal Thermo-Elements which we manufacture.

ENGELHARD

Thermo-Elements are made in four types, covering every industrial use.

PLATINUM

90% Platinum, 10% Rhodium

Unequalled for temperature measurement up to 1600° C. Interchangeability from element to element and lot to lot guaranteed within limits of 3° C. Recommended wherever accurate measurement of temperature is required; especially glass and ceramic plants. While first cost is several times higher, life is much more than proportionately longer and used elements may be reclaimed.

IRON-CONSTANTAN

Recommended for temperatures below 900° C., especially for uses in a neutral or reducing atmosphere. Interchangeability guaranteed between different thermo-couples and from lot to lot to within 5° C. When properly protected, there will be no trouble from parasitic currents.

CHROMEL-ALUMEL

Recommended for temperatures not above 1000° C., in neutral or oxidizing conditions. Interchangeability guaranteed within limits of 8° C.

COPPER-CONSTANTAN

Recommended for accurate temperature measurement where the thermo-electric system is most convenient, range not to exceed 200° C. Considered the most accurate base metal couple developed. Interchangeability to within 5° C. for very accurate work in small areas where quick readings are desired, may be mounted in series.

Regardless of your need, whether where initial temperatures requiring accuracy are involved, or in any other temperature range, it will pay you to obtain your thermo-elements from us because of our unequalled research facilities in this field. Many industries throughout the nation have come to us with their element problems and through our experience have profited in obtaining the desired results.

Complete data, temperature tables and insulation recommendations sent promptly upon request.

CHAS. ENGELHARD INC.

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Recording and Indicating instruments automatic temperature and gas control, pyrometers, gas analyzers, thermo-couples, thermometers.

STANDARD FOR 30 YEARS

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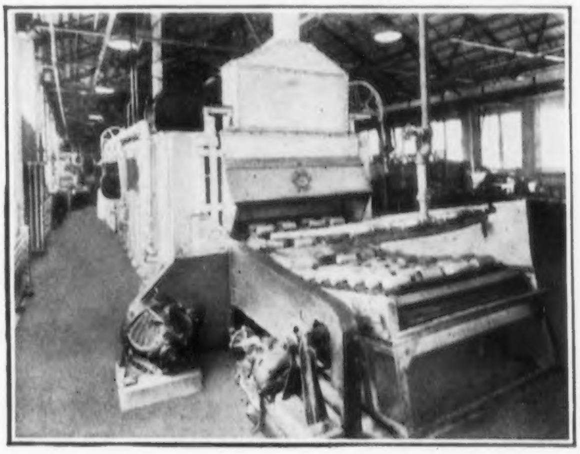
When writing to Charles Engelhard, Inc., please mention TRANSACTIONS

ROCKWELL FURNACES

ELECTRIC *and* FUEL



Heat-Treating Ferrous and Non-Ferrous Metal Parts—*Without Trays*

in a manner that permits of individual exposure and continuous charging and discharging of the unit pieces is but one of the many features offered in the furnace illustrated above.

Stock to be heated may be charged at random, movement through the furnace without distortion being accomplished with a special form of alloy metal conveyor. Heated stock may be delivered to a shower or bath for cooling from inside the furnace chamber or through the working opening.

In economy of operation and quality of heat-treated product this furnace has shown marked superiority over methods previously employed and we would welcome an opportunity to tell you more about it.

Write for Bulletin 280-C

New York
Detroit
Chicago

Montreal, Canada:
358 Beaver Hall
Square

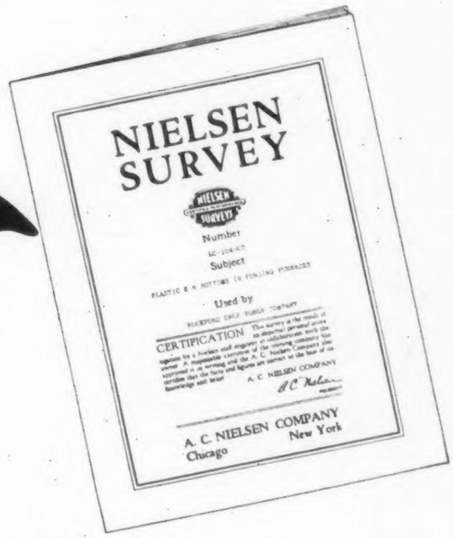
Member of Industrial Furnace Manufacturers Association

Rockford Drop Forge Co.

Saves $6,840.66 per year by using

LAVINO (K-N) Plastic (K-N) LAVINO

—and this Survey tells how



Write for your copy of Survey No. LC-104-CZ.

PLASTIC K-N is properly prepared Chrome Ore in "Plastic Form." It is shipped "ready for use" in steel containers of 200 lbs. Net Wt.—209 lbs. Gross Wt. PLASTIC K-N is the most permanent and reliable "Plastic" Refractory for Monolithic Furnace Bottoms and Molding Burner Blocks,—and it is easily installed by unskilled labor.

THE Rockford Drop Forge Company, Rockford, Ill., operates 46 oil fired furnaces at temperatures from 2300 to 2400 Degrees F. They formerly used Fire Brick bottoms in all these furnaces—encountered the following disadvantages: Short Life (about 2 Months)—Weekly Repairing and Patching necessary—Excessive amount of slagging.

Two years ago the Rockford Drop Forge Company started using PLASTIC K-N—today they USE IT EXCLUSIVELY in all their furnace bottoms—with the following "proven results": Long Life—Low Upkeep Costs—Freedom from Slagging.

To be brief, they SAVED 57% PER FURNACE PER YEAR, BY USING PLASTIC K-N, instead of Fire Brick and Clay.

Distributors in Principal Cities

E.J. LAVINO AND COMPANY

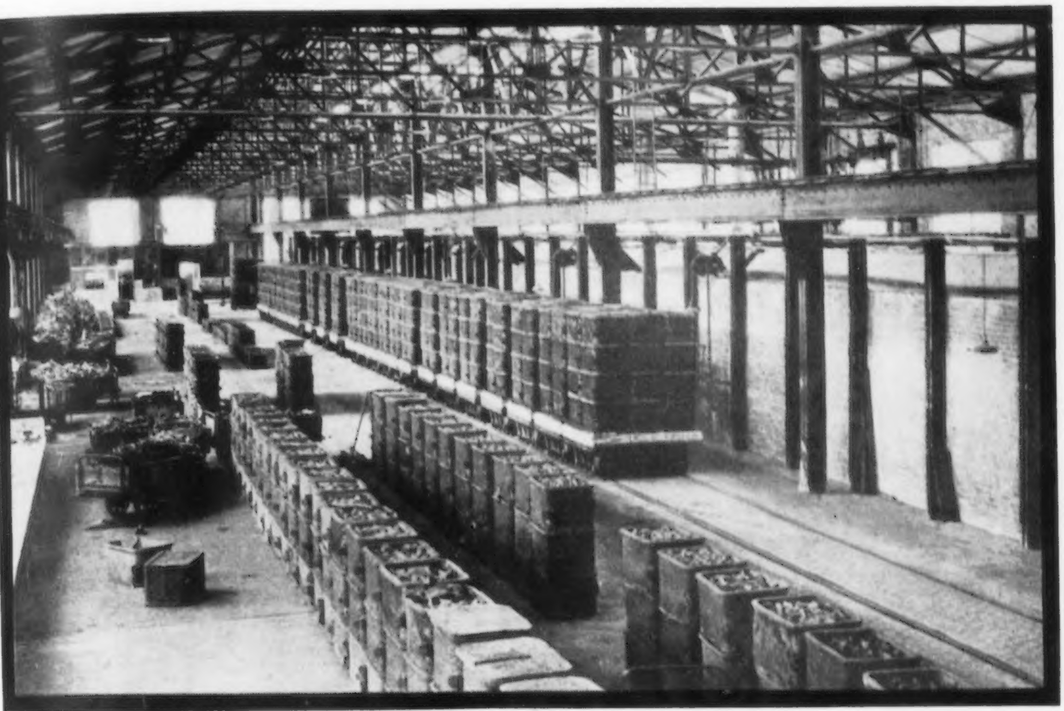
REFRACTORIES DIVISION

CHROME, MAGNESITE AND SILICA REFRACTORIES

BULLITT BUILDING PHILADELPHIA

"Pioneers in Chrome Refractories"

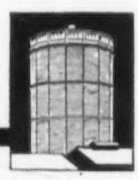
IF IT'S DONE WITH HEAT, **YOU CAN DO IT BETTER WITH GAS**



THE tunnel kiln has revolutionized many branches of the ceramic industry. Ten years ago tunnel kilns were practically unheard of; today hundreds are in use. And it is generally acknowledged that gas heat is in a large way responsible for the development of the tunnel kiln to its present state of efficiency. Tunnel kilns are essentially gas-burning equipment.

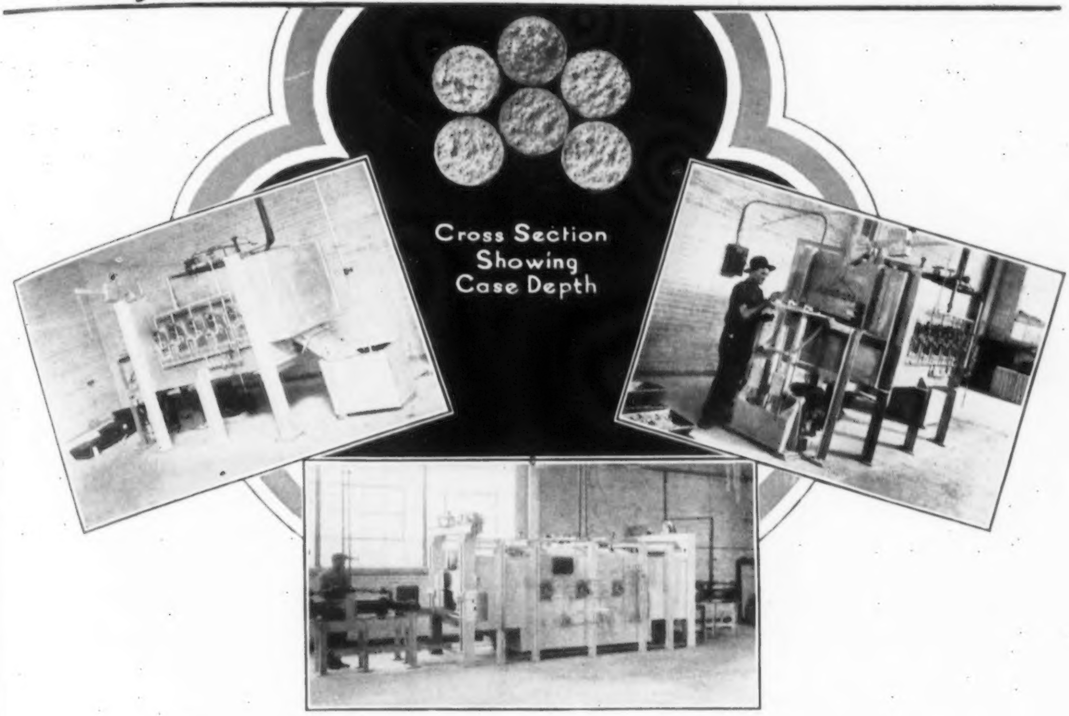
Send for your copy of the free book, "GAS HEAT".

AMERICAN GAS ASSOCIATION
420 Lexington Avenue, New York




Utica progressive perforating, blanking and forming punch
UTICA
OIL-HARDENING TOOL AND DIE STEEL
UTICA is a tungsten alloy tool steel having several excellent characteristics. It is deep hardening, develops a high degree of hardness, and has marked non-deforming properties. It will maintain a keener and more lasting cutting edge than straight carbon tool steel and is designed for extremely heavy work.
Utica is especially suited for taps, threading tools, reamers, drills, and broaches. It is also recommended for press tools, particularly for punches and dies of complicated shape.
Let us send you the Ludlum Tool Steel Catalog giving applications and treatments for the entire Ludlum Line.
LUDLUM
LUDLUM STEEL COMPANY
WATERVLIET AND DUNKIRK, N. Y.
TOOL AND SPECIAL ALLOY STEELS
NIROSTA, NITRALLOY & STRAUSS METAL

Again SC Furnace Results Win



the Approval of Industry

by carburizing fan shafts to .030" case depth with reheat and quench to harden

"METALLURGICAL specifications are met, exactly, with our SC Special Furnaces"—says the superintendent of the Automotive Fan and Bearing Company of Jackson, Mich.

The shafts are not only case hardened to a depth of .030", but after reheating and hardening, the surfaces are remarkably free from scale, and show a uniform carbon penetration with a Rockwell hardness of 60.

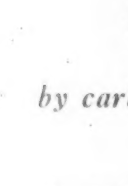
All of this is accomplished by two SC Special Furnaces at the rate of 4000 shafts per 20 hr. day on a total of 995 cu. ft. of gas per hour.

The carburizing furnace, continuous type, with counter flow travel, pushes the sheet alloy containing boxes through the furnace, at intervals of 1 hr., on cast alloy trays mounted on alloy rails.

The unusual fuel economy obtained (approximately 675 cu. ft. of 530 B. T. U. gas per hour, carburizing 430 lbs. gross, per hour at 1650° F.) is due to the SC automatic proportioning two-stage velocity burners, and scientific construction employed in the furnace design.

The shafts are reheated, after carburizing, to 1480° F. in a SC v-notch pusher type continuous furnace — then water quenched to case harden. Two stage, automatic proportioning, SC Burners regulate the temperatures in the heating and reducing zones, thereby reducing scale formation to an absolute minimum. 200 shafts are hardened every hour on 320 cu. ft. of 530 B. T. U. gas.

The same assurance of satisfaction can be given you on your heat treating operations. Write for complete information.



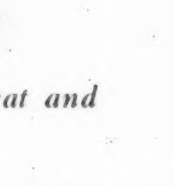
The Surface Combustion Co.

INCORPORATED
Subsidiary of Henry L. Doherty & Co.
2375 DORR STREET, TOLEDO, OHIO
Branch Offices in All Principal Cities

Mantle Recuperator Division — METALLIC RECUPERATORS

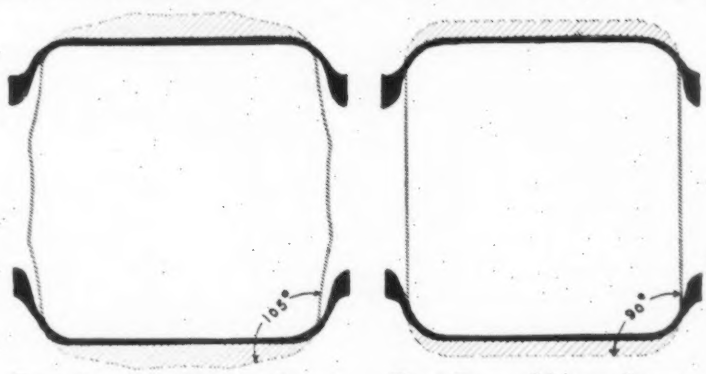
Webster Engineering Co — WEBSTER BOILER BURNERS

Member of Industrial Furnace Manufacturers Association



When writing to The Surface Combustion Company, please mention TRANSACTIONS

Initial Reduction Pass Indicates Surface Condition of the Finished Bloom



First Pass Gathmann Ingot Corner Reduction Light — *First Pass old type Ingot Corner Reduction Heavy*

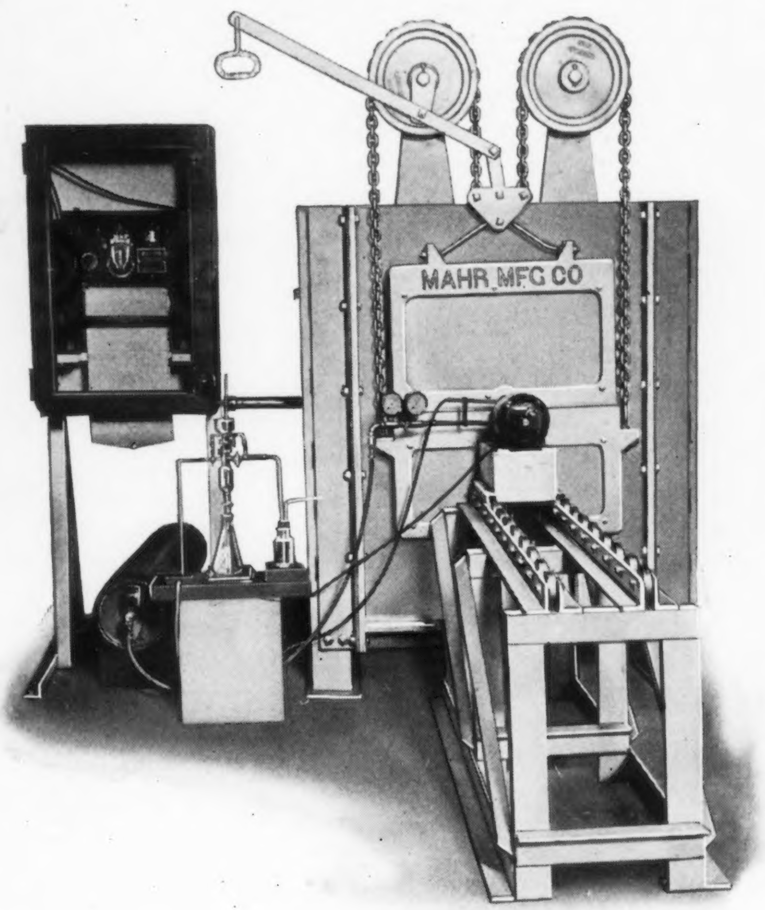
IT WILL be clear to the engineer from a study of the above contours why the new Gathmann ingot cross section solidifies and rolls to such advantage.

In solidification the skin of the ingot is flexible and the entire mass is free to contract without danger of the skin breaking.

In rolling of the ingots, the relatively narrow primary sides are swedged outwardly to a large extent parallel with the axis of the rolls rather than stretched or flowed longitudinally. The free, unworked adjacent sides are thus deformed only slightly, if at all, during the initial pass in the rolls.

Give us an opportunity to discuss your ingot designs and rolling mill problems. Our recommendations are entirely without obligation.

The
GATHMANN ENGINEERING CO.
"Designers of Ingot Molds"
BALTIMORE, MARYLAND



Mahr Nitriding Furnaces

CASE hardening by nitriding develops a hardness in steels not obtained by any other case hardening process. The case of these steels have a Brinell hardness several hundred points higher than the maximum figures obtained with steels hardened by ordinary case hardening and quenching methods.

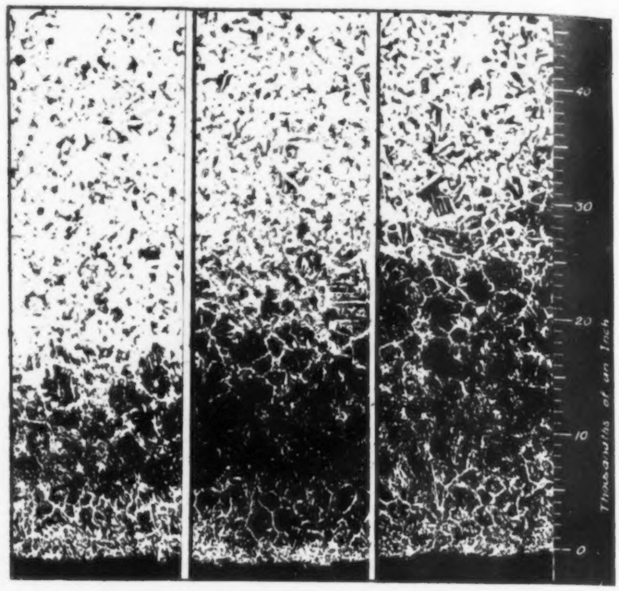
Nitriding is carried out at low temperatures so that there is practically no difficulty with deformation, distortion and cracking of the steel.

Our engineers are prepared to show you where nitriding can be used to advantage in your manufacturing process.

MAHR MANUFACTURING COMPANY
Minneapolis, Minnesota
Offices in Principal Cities

MAHR

INDUSTRIAL OIL AND GAS BURNING EQUIPMENT



One Hour Two Hours Three Hours

This Uniformity is Typical with the AEROCASE PROCESS . . .

THESE photomicrographs show the uniform carbon penetration obtainable by the Aerocase Process. S. A. E. 1020 steel bars were treated in the bath at 1600 degrees F. Specimen bars were removed after 1, 2, and 3 hours respectively. The treated samples were cooled in lime; polished and etched. These results may be secured regularly in your hardening department, *in one-third the time required by any other process.*

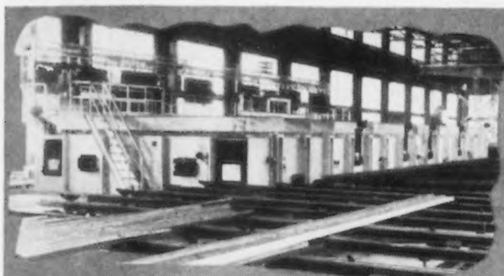
The Aerocase bath consists of Compound No. 510 to which is added activating Compound No. 28 supplied in 2-1/3 oz. blocks. The bath strength is readily maintained and carbon is released to steel quickly and evenly. A remarkable freedom from bath fumes is noticeable. Better, more rapid, and more economical hardening is inevitable.

There is one sure way to save time and to be assured of consistently uniform results in your hardening department—use Aerocase—the Advanced Hardening Process. Let us know your requirements and we will tell you how to meet them more economically with Aerocase.

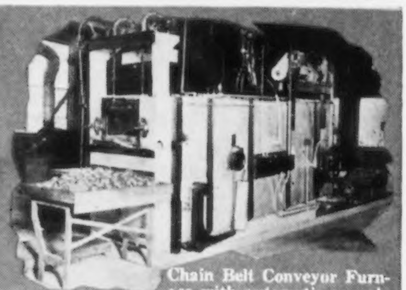
Industrial Chemicals Division

American Cyanamid Company

535 Fifth Avenue New York



Walking Beam Furnace Heat Treating Aluminum Shapes up to 90 feet long.



Chain Belt Conveyor Furnace with automatic quench, Hardening Bearing Races.

Vertical Pit Furnace Annealing Alloy Steel Bars.

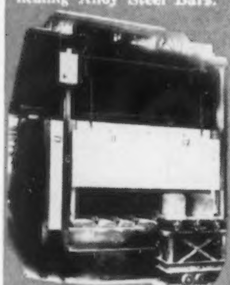
Circular Pit Type Furnace Annealing Wire in Coils.

Furnaces

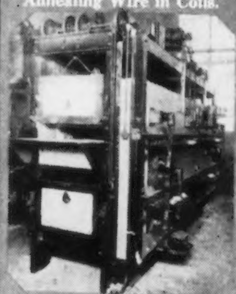
Regardless of the size, shape, or weight of your product, the *accuracy* of treatment or *tonnage* required, we can build a furnace to handle it uniformly, economically, and to meet your production schedules.

Practically everything from small steel balls for bearings to large pressure vessels *67 feet long* are being successfully handled in our furnaces.

The Electric Furnace Co.
Salem, Ohio

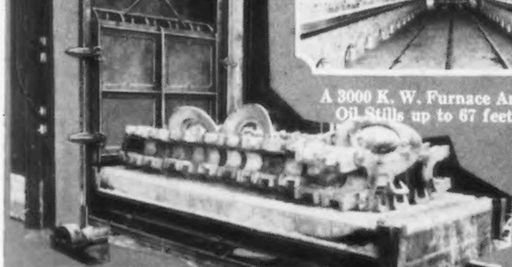


Thru Type Counterflow Recuperative Carburizer.

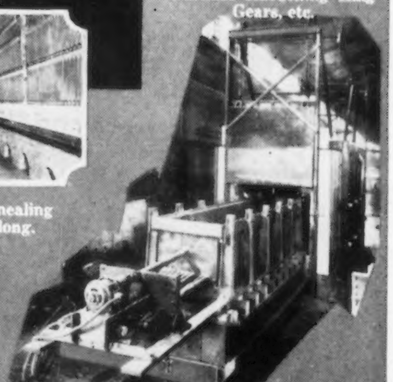


Double Deck Roller Hearth Furnace Hardening Ring Gears, etc.

A 3000 K. W. Furnace Annealing Oil Stills up to 67 feet long.



Single Chamber Car Type Furnace Annealing Steel Castings.



A Special Car Type Nitriding Furnace—Handles parts from 1 Inch to 22 Feet long.

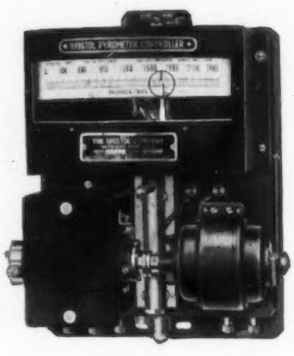
. . . . Guaranteed Uniform quality secured the order.

Automatic Temperature Control as Your Sales Aid

THE enthusiasm and confidence which comes from knowing that one's product is *right,* is soon reflected in the sales record.

For example, improvements in production methods made possible by automatic control of heat treating temperatures, has a very close relation to selling.

Such control assures correct processing of work day after day, month after month; with elimination of spoilage, reduced labor cost, minimum fuel expense, etc. It is therefore very apparent that not only will the quality of product be consistently more uniform, but the saving effected may legitimately be applied to lowering the selling price to consumers. This gives the salesman a *double advantage* of both *price* and *quality.*



Bristol's Pyrometer Controller. For ranges of Temperature up to 3000° F.

Bristol's Automatic Control Equipment can be installed to operate equally well on oil, gas or electrically heated furnaces, ovens, etc. Designed especially for control work, all operating parts are ruggedly constructed, and as proven by thousands of successful installations, Bristol's equipment is capable of continuous trouble-free operation.

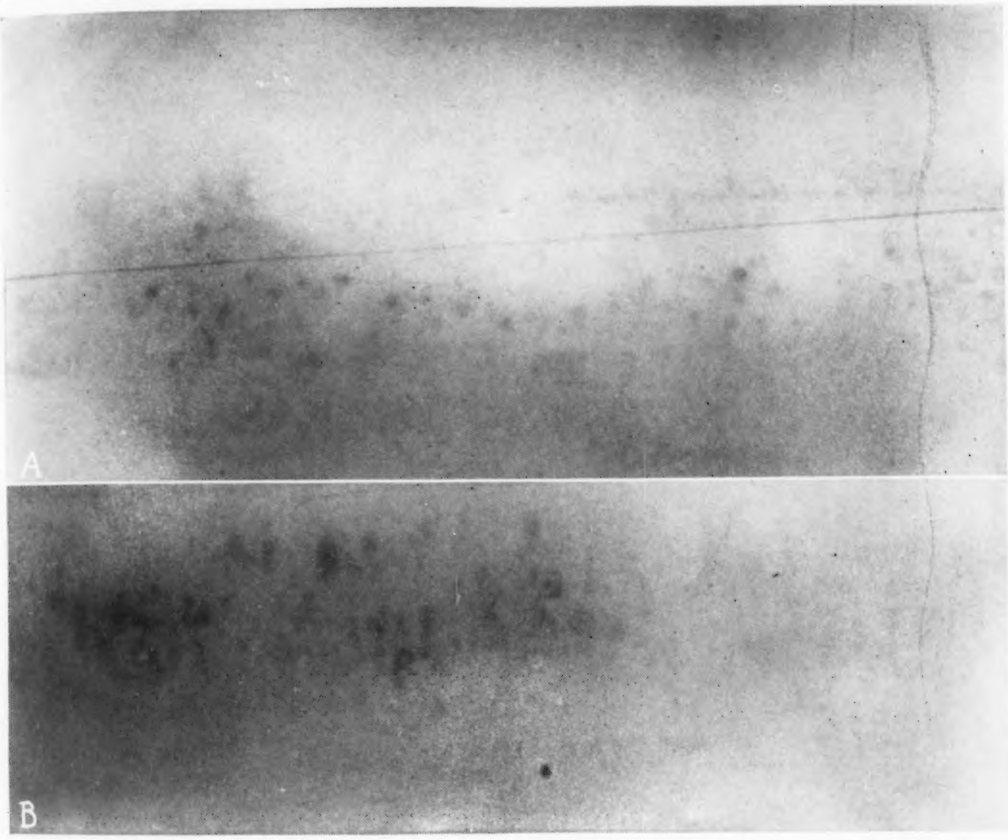
Without obligation to you, Bristol's Sales Engineers are available to make a survey of temperature control possibilities in your plant.

The Bristol Company

Waterbury, Connecticut

Branch Offices

Boston New York Philadelphia Pittsburgh Akron Birmingham Detroit
Chicago St. Louis San Francisco Denver



Can you use the X-Ray profitably?

An invitation to submit your problem to us

A Radiograph of a weld of steel 1¾" thick, that had been previously examined by sectioning (note the fine line in the radiograph). The surfaces after sectioning showed only two small gas holes, but this radiograph revealed many more holes.

B This radiograph was then made at 90° to the surface of one section, definitely locating the position of these holes.

Thus radiography is used to detect an incorrect practice in welding.

THE value of radiography in metal examination is no longer questioned by leading investigators. Just how practicable it is for you can be determined only by close study of your problems. We welcome the opportunity to collaborate with you in making such experiments as will show whether an x-ray laboratory would be profitable to you.

With the extensive facilities of our experimental laboratory, and a practical knowledge gained through helping others toward the solution of problems with the x-ray, we are in a position to give reliable advice on the industrial use of radiography.

Careful attention will be given requests for further information.

GENERAL ELECTRIC
X-RAY CORPORATION
2012 Jackson Boulevard Chicago, Ill., U. S. A.
FORMERLY VICTOR X-RAY CORPORATION

Join us in the General Electric hour, broadcast every Saturday evening over a nationwide N. B. C. network

BETHALON

NON-RUSTING and machines like ordinary screw stock!

Just what you have been looking for! An easy-machining, stainless metal to use in making the countless automatic screw-machine parts in which immunity to corrosion is highly desirable. Bethalon is completely immune to corrosion from ordinary influences; can be machined as easily as ordinary screw stock; and in addition possesses an exceptionally desirable combination of physical properties.

150 surface feet per minute . . . .

This bushing, made of BETHALON, was machined at the speed of 150 surface feet per minute, which is exceptionally high for a stainless metal.

You are invited to try this new, free-machining, stainless metal in your automatic screw-machines and see for yourself how smoothly it goes through without changing the feed, speed, depth of cut, or altering the set-up in any way whatsoever. Subject Bethalon to the highest test of machinability—drilling and boring. If you have ever before tried machining stainless steels you will get a surprise. The behavior of Bethalon under drilling and boring operations has astonished men who have experienced the difficulties that ordinarily attend the machining of stainless steels.

Bethalon is a Bethlehem product developed in the Bethlehem Tool Steel Laboratories and made in the Bethlehem Tool Steel Plant.

BETHLEHEM STEEL COMPANY

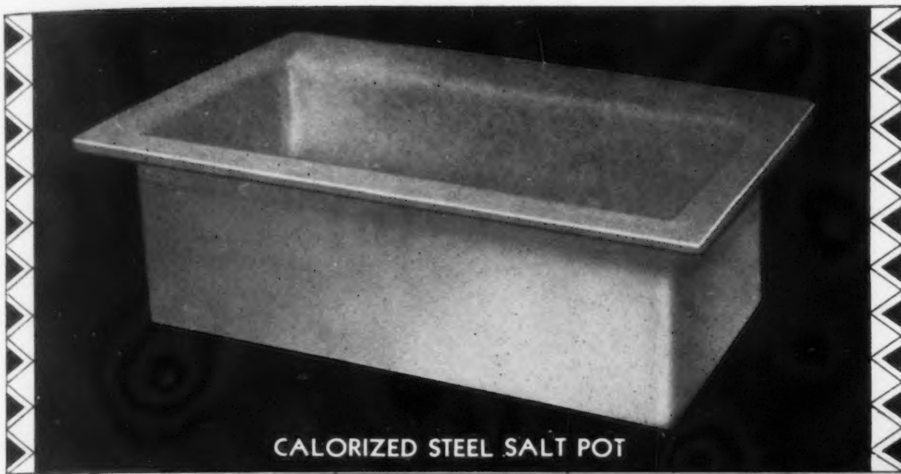
***General Offices:* Bethlehem, Pa.**

District Offices: New York, Boston, Philadelphia, Baltimore, Washington, Atlanta, Pittsburgh, Buffalo, Cleveland, Cincinnati, Detroit, Chicago, St. Louis.

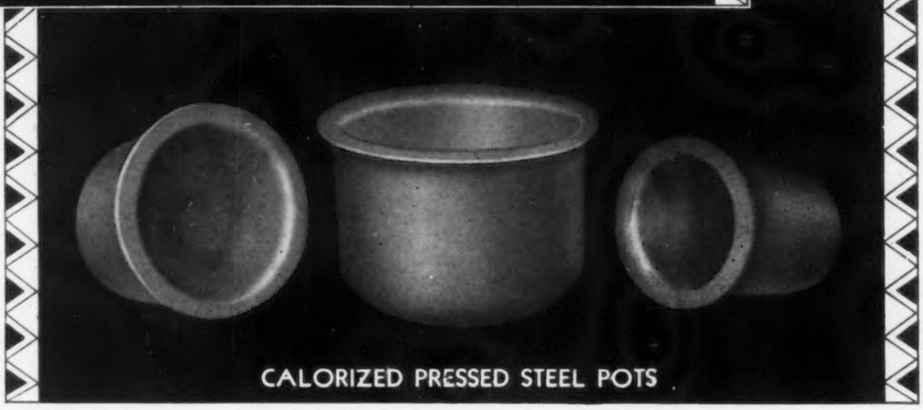
Pacific Coast Distributor: Pacific Coast Steel Corporation, San Francisco, Los Angeles, Seattle, Portland, Honolulu.

Export Distributor: Bethlehem Steel Export Corporation, 25 Broadway, New York City

BETHLEHEM



CALORIZED STEEL SALT POT



CALORIZED PRESSED STEEL POTS

REDUCE POT COSTS with CALORIZED STEEL

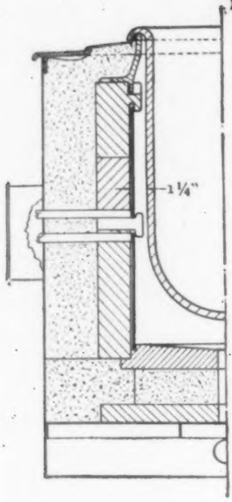
1. It is the most economical heat enduring material available.
2. Increases production — heat conductivity of steel maintained by Calorized surface.
3. Will not scale. (Scale reduces heat transfer).
4. No pot leaks due to porosity as in cast steel or alloy containers.
5. Calorizing costs less than the plain steel container—
6. But a Calorized pot will outlast three or four plain ones.

THE CALORIZING COMPANY

WILKINSBURG STATION PITTSBURGH, PA.

TRENT

heat generated within 1¼" of work . . .



. . . thus getting a greater part of every kw. actually into the work than has ever been done before. By using walls having combined insulating and refractory powers, waste radiation is almost negligible—hence, quicker starts and less loss while standing idle.

It's all told in Bulletin TB-20

Harold E. Trent Co.

443 N. 12th Street, Philadelphia, Pa.

Manufacturers of

Electrically Heated TRENT TRADE MARK *Industrial Equipment*

Pittsburgh Boston Buffalo Chicago Cleveland Detroit
San Francisco Seattle St. Louis Los Angeles Minneapolis

THERMIT TRADE MARK REG. U.S. PAT. OFF. GOLDSCHMIDT PATENTS

Automobile and other Alloy Steel Specifications are becoming more and more exacting.

It is necessary, therefore, to use the highest grade of raw materials entering into the construction of automobiles, machine parts, etc.

In the manufacture of our various metals and alloys, we must use, and do use, the highest grade of ores, oxides and aluminum.

Tungsten Powder	97-98%	Pure Chromium	97-98%
Pure Manganese	96-97%	Ferro-Tungsten	75-80%
Ferro-Chromium	60%	Ferro-Titanium	25%

Ferro-Vanadium 35-40% (1% Silicon)

Send for Pamphlet No. 2021

METAL & THERMIT CORPORATION

120 Broadway, New York City

Pittsburgh Chicago S. San Francisco Boston Toronto

The SERVICE *back of* PYRASTEEL

A LARGE manufacturer of farm machinery needed 80 Pyrasteel carburizing box pusher covers at once. These covers weigh 50 lbs. each.

On Thursday morning the order was received, and 25 covers had to be delivered by Saturday morning.

On Friday, 48 covers were cast and 25 were cleaned and shipped the same day by package car to a delivery point 200 miles distant.

On Saturday, 23 covers were shipped and the balance of the order completed by the following Tuesday noon.

That is our idea of service.

For resistance to corrosion, oxidation, abrasion and for high tensile strength at high temperatures.

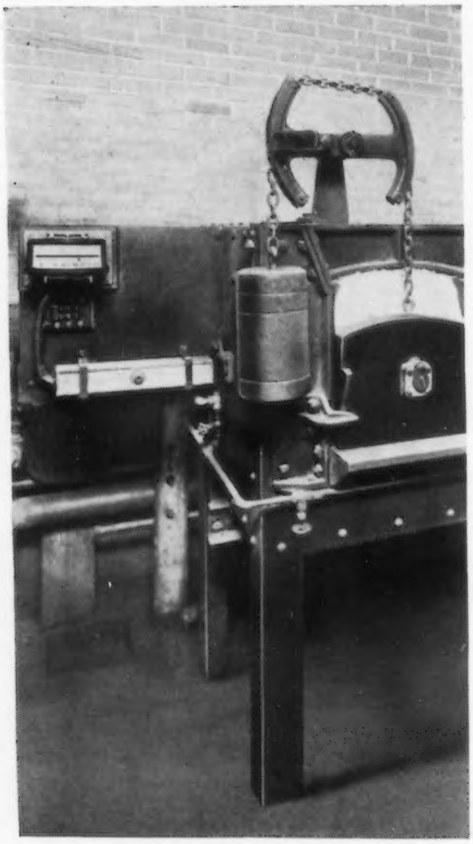
CHICAGO STEEL FOUNDRY COMPANY
Makers of Alloy Steel for Over Twenty Years
Kedzie Avenue at 37th Street, Chicago, Illinois

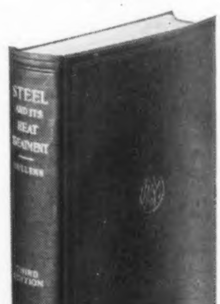
PYRASTEEL
for high temperatures

Agents in New York, Philadelphia, Indianapolis, Tulsa

CHICAGO STEEL FOUNDRY COMPANY
Kedzie Avenue at 37th Street, Chicago, Ill.
Send me a copy of your booklet on PYRASTEEL.

Name..
Firm..
Street..
City and State................................





9600-lb. Nickel Cast Iron

gas engine cylinders are long wearing . . . pressure tight!

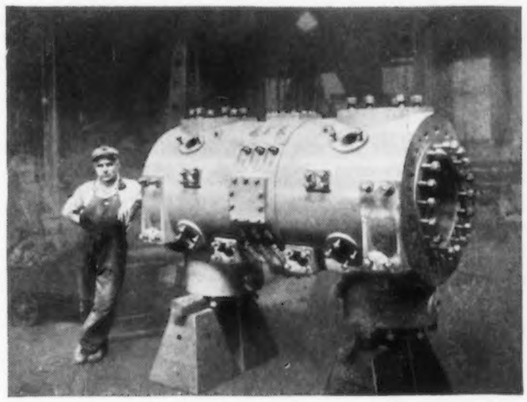
A LARGE GAS COMPANY is now operating over ninety 20″ x 36″ gas engines manufactured by the National Transit Pump & Machine Company. In such service the possibility of shut-downs for repairs must be reduced to a minimum, and therefore the selection of materials having the highest degree of wear-resistance is of utmost importance. Density, adequate strength and toughness are essential to the satisfactory performance of castings used in such a unit.

The National Transit Pump & Machine Company is providing longer uninterrupted service in its units by the use of scientifically correct Nickel Cast Iron.

Two 9600-pound cylinders, with removable cylinder liners included in the assembly of one of the units, are produced from Nickel Cast Iron. The cylinders are uniformly dense throughout the various sections and are also readily machinable.

The Nickel Cast Iron liners have given from two to two and a half times the life of the conventional gray cast iron in this severe service. Not only are these liners satisfactorily resisting piston ring wear, but they are also standing up extremely well under the intense heat generated by the combustion of the gas. The National Transit Pump & Machine Co. states that since the adoption of Nickel Cast Iron fire cracks and acid abrasion have been eliminated.

Nickel FOR SCIENTIFICALLY CORRECT CAST IRON

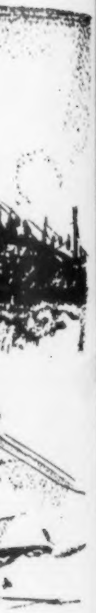


Upper right: Nickel Cast Iron 20″ x 36″ power cylinder used in gas engine. Below: 20″ x 36″ gas engine manufactured by NATIONAL TRANSIT PUMP & MACHINE CO., Oil City, Pa.

INCO F NICKEL

Our foundry specialists will gladly discuss your casting problems with you.

THE INTERNATIONAL NICKEL COMPANY, INC., 67 WALL STREET, NEW YORK, N. Y.



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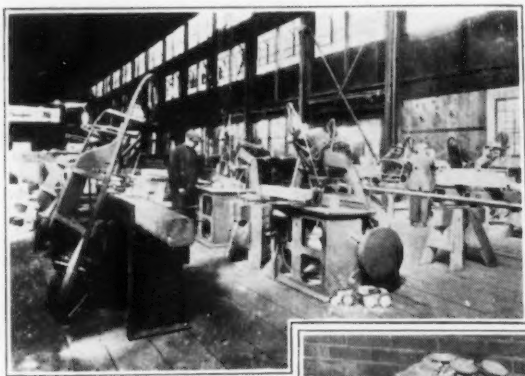


Part of Equipment Used Exclusively for Cutting Discs for Inspection.

A Typical Day's Work in the Disc Inspection Dept.

What DIOK Means To You

Briefly, it means better tools and better dies that will give you longer service and reduce your production costs.

It will end the needless waste of time and money spent in the tool room on inferior or defective material, only to see it go bad in hardening or prematurely fail in use.

DIOK prevents this because it eliminates all guess work and replaces it with the knowledge that every bar is uniform and free from defects and impurities.

It is Carpenter's pledge to its customers that all tool steel bearing the familiar DIOK label has been disc inspected at the mill by Acid Etch and hardening tests. DIOK is not the name of a steel, but a certificate of inspection.

Specify DIOK when you order high-grade water hardening or oil hardening tool steels. They are instantly available from Carpenter warehouse stocks—at no premium in cost.

Do you have a copy of Technical Bulletin "B" on Hot Acid Etching—telling how to do it—what it shows—what it means? We will send it gratis upon request.

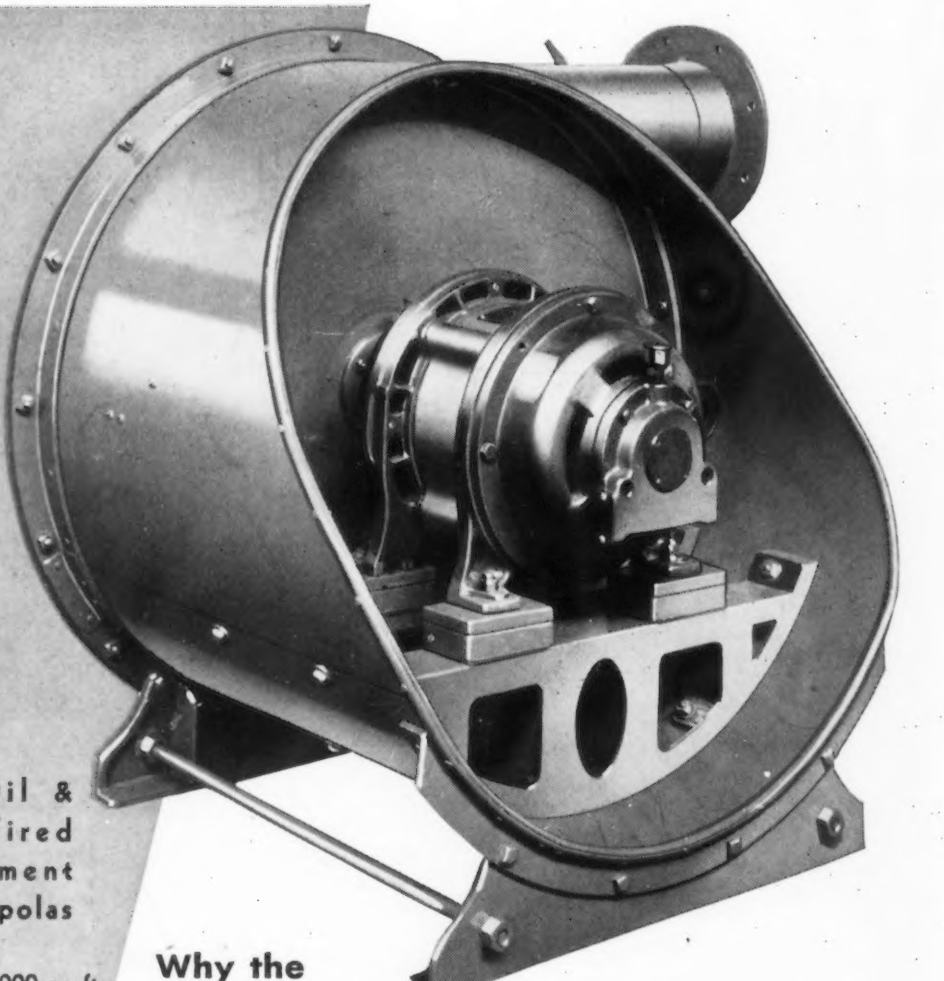
THE CARPENTER STEEL COMPANY

Mills and Main Warehouses: READING, PA.

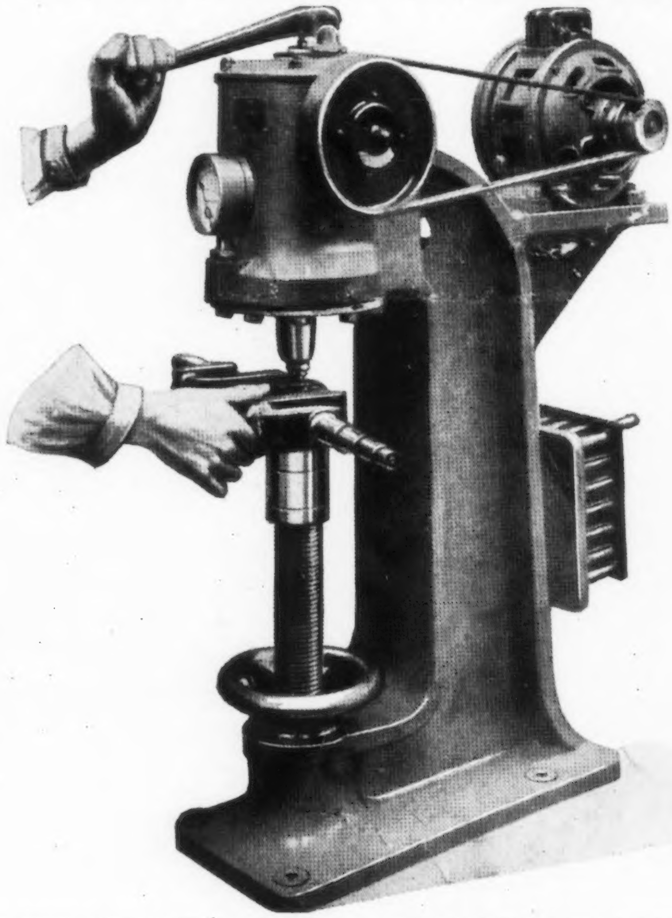
Branch Warehouses:

CHICAGO 1516 Carroll Ave.	**DETROIT** 6181 Warren Ave. W.	**INDIANAPOLIS** 633 Fulton Street
CLEVELAND 1515 Hamilton Ave.	**HARTFORD** 3284 Main Street	**ST. LOUIS** 4063 Forest Park Ave.

PHILADELPHIA, Horace T. Potts & Co., East Erie Ave. and D St.



TESTING MACHINES



REASONS FOR GREATER ACCURACY OF BRINELL HARDNESS DETERMINATION SECURED WITH OUR TYPE 03 POWER OPERATED BRINELL TESTING MACHINE.

1. Elimination of friction plungers.
2. Elimination of human element in developing desired pressure.
3. Dirt and dust proof.
4. Free and frictionless pressure control.
5. Speed of load application arranged to secure consistently accurate results.
6. Simplicity of construction and operation.

Why They Will Accomplish Far More Tests than any Other Machine on the Market.

1. Can be operated by foot pedal, giving the operator free use of both hands for inserting and removing specimens.
2. Machine can be mounted on truck and moved from place to place, saving necessary handling of tons of material.
3. Can be operated wherever a light socket is available or a connection to the plant power line.
4. Where a large number of specimens of same kind are to be tested, work table can be set allowing ⅛" between specimen and ball as ram has enough travel to come down, make the impression, and immediately return to its home position.
5. Number of tests possible per hour, at least 1000.

We have the exclusive sale of the Southwark-Emery Universal Testing Machine for Tensile, Compression and Transverse Testing, also Torsion Testers.

STEEL CITY TESTING LABORATORY

8843 Livernois Ave. **Detroit, Michigan**

The Cincinnati

METALLOGRAPHIC POLISHING MACHINE ~

A New Standard of Efficiency

HERE is THE CINCINNATI Metallographic Polishing Machine that has set a new standard of efficiency in the polishing of metal surfaces for microscopic examination. THE CINCINNATI Metallographic Polishing Machine is equipped with a variable speed motor which gives a range of speeds between 300 and 3000 RPM.

Smoothness of operation—a feature that cannot be secured in a machine having a friction or belt drive is achieved with THE CINCINNATI Polishing Machine—even an inexperienced operator can get an absolutely scratch-free surface. There are no belts or friction disks to slip—no excessive vibration or noise—no splashing of polishing material.

The bowl, disc and ring, together with all other small parts are made of cast bronze which resists corrosion and thus eliminates the danger of rust particles interfering with the polishing.

May be had for alternating current, 110 or 220 volts, 60 cycles, 1 phase or direct current 115 or 230 volts.

A Few Users of THE CINCINNATI Metallographic Polishing Machine

American Sheet & Tin Plate Co.
Crucible Steel Company of America
Aluminum Company of America
U. S. Naval Aircraft Factory
American Rolling Mill Company
Carnegie Steel Company
Federal Shipbuilding & Dry Dock Company
Department of Mines, Ottawa, Canada
Summerill Tubing Company

Write us for Bulletin S7 giving complete specifications

The Cincinnati Electrical Tool Co.

CINCINNATI, OHIO

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